Strengthening the information base of natural habitats, biodiversity and environmental services in the Shire Basin

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Year 1 Analytical Report - DRAFT

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Executive Summary

Background

"Strengthening the Information Base of Natural Habitats, Biodiversity and Environmental Services in the Shire Basin" is a component of the Shire River Basin Management Program. We will hereafter refer to this component as the Natural Habitats Surveys activity. The overall objective is to establish a comprehensive, up-to-date and high quality inventory of the status of natural ecosystems and species in the Shire River Basin, and to improve information about the value of the ecosystem products and services they provide. This information will be made available in a range of communication formats suitable for informing resource planning and management at the basin level and at key biodiversity sites. Another important objective of the activity is to foster capacity-building, knowledge exchange, and partnership development with key institutions in Malawi that are concerned with the management of natural habitats and species, including the Forest Research Institute of Malawi (FRIM), the National Herbarium and Botanic Gardens (NHBG), and the Department of National Parks and Wildlife (DNPW).

Year 1 Activities and Deliverables

Activities undertaken during Year 1 were sequenced as follows:

- Inception mission (16-21 March 2015)
- Inception Report (accepted August 2015, following incorporation of comments on drafts)
- Assessment of existing information on natural habitats and biodiversity
- Site selection workshop and Rapid Botanic Surveys (RBS) training (1-5 June 2015)
- Natural habitats surveys using RBS methodology (June-August 2015)
- Data entry and analysis (Sept-Oct 2015)
- Presentation of Year 1 Results and Year 2 Work Planning (16-20 November 2015)
- Submission of spatial data and related information for SRB Atlas and Portal (4 December 2015)

Areas and sites for natural habitats surveys were selected by a working group of Natural Habitats Surveys team members, international consultants, and staff of FRIM and NHBG who have worked extensively in the Shire Basin. Criteria for site selection included: whether a site is located in a protected area (e.g., forest reserve, national park); is outside of a protected area but with significant natural vegetation; already has a strong information base on vegetation status and/or species; has potential as an ecological corridor; is within a SRBMP priority catchment; and/or is relevant to resource planning and management at basin level. A site-selection matrix using these criteria, along with high resolution, up-to-date satellite imagery of the Shire River Basin, was used to select the areas and sites to be sampled. The following areas were selected: Mangochi FR, Tsamba FR, Neno East Escarpment (proposed FR), Liwonde FR, Zomba-Malosa FR, Lengwe NP, Chingale catchment, Kapichira catchment, Lisungwi catchment, Upper Wamkulumadzi catchment, Thambani FR, Matandwe FR, Mwabvi WR, and "sites known to harbour important biodiversity in Thyolo Tea Estates".

We used the Rapid Botanic Survey (RBS) methodology, which allows a high percentage of all plant species occurring at a sample site to be collected very rapidly. RBS methods integrate species and community-level assessments of plant biodiversity, and RBS data are used to determine the main patterns of floristic variation across a landscape. New samples collected using the RBS methodology often fill gaps in knowledge about plant distribution. Analysis of plant samples can be used for mapping vegetation and prioritising areas for different management purposes.

Field surveys sampled vegetation at 52 locations in 12 protected areas and other areas of significant natural vegetation throughout the Shire Basin between June-August 2015. This greatly exceeded our initial sampling proposal outlined in the Inception Report. Specimens were processed and identified at NHBG in Zomba. Plant data were entered into a botanical database, the Botanical Research and Herbarium Management System (BRAHMS), which enabled detailed statistical analysis of vegetation composition and other characteristics. Approximately 4,700 photographs were taken during the field surveys, providing strong photo documentation of the vegetation at each site, and its condition.

Analysis of the botanical information from the RBS plant surveys was used to classify the vegetation at each site, assess its the condition based on the presence and abundance of canopy tree species, and determine the presence of globally-rare, restricted range species. Such information can support the objectives of the Natural Habitats Surveys activity by providing up-to-date and high quality information that can inform management decision-making in the Shire River Basin.

Results

Geospatial analysis, modelling, and mapping during Year 1 produced a range of maps for the Shire River Basin Atlas and web Portal. Maps included potential natural vegetation, land cover and land use, natural forest and woodland cover, and risk of habitat loss from human activities.

A second, and most important, category of results produced by the Natural Habitats Surveys component of the SRBMP during Year 1 is based on the analysis of the plant samples collected throughout the Basin. A total of 1,134 species were identified among the approximately 4,200 specimens collected at the 52 sampling sites. Because a large majority of all species found at each sampling site were collected and identified, the RBS data give a reasonably complete sample of plant species diversity in the SRBMP project area. Information about species diversity is important for a number of reasons, but in the case of the SRBMP and its objectives, the main importance has to do with the relationship between species diversity, ecosystem function, and the ecosystem services that natural ecosystems provide to people. Recent ecological research points toward a positive relationship between species diversity and the stability or resilience of ecosystem functioning.

Using a statistical technique called ordination, vegetation from our sampling sites could be classified into eight main vegetation types. Elevation and precipitation were the main factors influencing the distribution of these vegetation types.

Disturbance of a natural habitat, such as direct human use of trees and other plant species, or fire, influences the composition and physical structure of the vegetation. In the analysis of data from the 52 sampling sites, ordination showed that the relative abundance of large tree cover can provide a measure of the level of human use or "disturbance" at the site. In three sparse woodland sites, ordination analysis showed that they have a very similar species composition to more intact miombo woodland. This suggests that if the factors that are removing large trees from the community (e.g., charcoal production) were controlled through management actions, tree cover could likely be restored through natural processes of woodland regeneration.

The presence of globally-rare, restricted-range species in our samples was determined by comparing them with a database of such species. Data from all 52 RBS samples showed the following numbers of range-restricted species: 36 species were most restricted/globally-rare; 53 were somewhat restricted/ rare; 262 were of intermediate range/commonness; and 741 were common and widespread. The highest level of globally-rare, restricted range species was found in montane grassland on Malosa Mountain, and high-elevation sites tend in general to have more globally-rare, restricted-range species than lower elevation sites. Even some higher-elevation miombo woodland sites harbour species of significant global uniqueness. The significant presence of globally-rare, restricted range species in our samples is noteworthy. Although all black star species are globally rare, of those found during the surveys, 7 appear to be Malawi-endemic and 10 are near-endemic (i.e. found in Malawi but also in nearby countries close to their common border, such as some sites Mozambique, for example).

Institutional Capacity Building

As highlighted in our Inception Report, an important aspect of the Natural Habitats Surveys activity is to foster capacity building, knowledge exchange, and partnership development with key institutions in Malawi that are concerned with biodiversity management. Over the course of Year 1 we have worked closely with our host institutions, NHBG and FRIMi, to improve and strengthen their capacity. The site selection workshop and rapid botanic surveys (RBS) training conducted in Year 1 developed some of this capacity, through classroom and field-level training in the internationally-recognized RBS methodology, which is new to Malawi, and which allows very rapid yet detailed surveys of natural habitats and vegetation. Training was also conducted in the use of BRAHMS. Fifteen staff members from NHBG and FRIM were trained in RBS, and twelve of those participated in the field surveys during a period of eight weeks in June-August 2015, gaining valuable "hands-on" experience.

At the November presentation of Year 1 results in Zomba we used a short survey to better understand whether the RBS training and field experience was useful to the participants. One question we asked was: "Do you expect to use the skills and knowledge you learned in the RBS process in your work in the future?" Responses from the nine staff members who had participated in the fieldwork were strongly positive, with seven of the nine respondents saying that they definitely would use the RBS experience in their future work.

Conclusions and Recommendations

The Year 1 results of the Natural Habitats Surveys activity, including our geospatial analysis, modelling, and mapping results, and the results of the field-based surveys of plant biodiversity, provide the rationale for prioritizing our Year 2 work. The results suggest that our strategic focus should be on conducting further studies at five priority protected areas: Mangochi, Liwonde, Zomba-Malosa, Neno East, and Tsamba Forest Reserves. These five sites would be the highest priority for further studies in Year 2 for the following reasons:

- Mangochi FR – this area had two of the three sites with the highest levels of globally-rare, restricted range species found in our survey of the Shire Basin, in montane evergreen forest and montane grassland with *Protea*.
- Liwonde FR – this area had one of the three sites with high potential for the regeneration of miombo woodland, and a nearby site with a high level of globally-rare, restricted range species.
- Zomba-Malosa FR – this area had a site in high montane grassland with the highest level of globally-rare, restricted range species of all 52 sites sampled, a level comparable with

other "hot" sites globally. It also had one of the three sites with high potential for the regeneration of miombo woodland, and a nearby site with a high level of globally-rare, restricted range species. Those sites were also in the Chingale Catchment, one of the four Priority Catchments of the SRBMP.

- Neno East Escarpment (proposed FR) – had one of the three sites with high potential for the regeneration of miombo woodland, and a nearby site with a high level of globally-rare, restricted range species.
- Tsamba FR – Sites in this area were generally well-conserved, presenting an example of intact miombo woodland, a "witness stand" against which the condition and regeneration of miombo woodland at other sites can be compared. The Tsamba FR is in the Upper Wamkulumadzi Catchment, one of the four Priority Catchments of the SRBMP

The types of studies we are proposing for Year 2 are summarized below. Given budgetary limitations, it is clear that not all types of activities can be carried out at all sites.

Further analysis of regeneration potential should be conducted at selected sites, with the goal of strengthening information about natural forest regeneration that can eventually inform management recommendations in the Shire River Basin, and develop knowledge product(s) to that end. Further studies to characterize natural regeneration potential in areas in Vegetation Class 2 in Liwonde FR, Malosa FR, and Neno East proposed FR should be conducted.

Further study of globally-rare/restricted range plants to characterize populations, inform management decisions, and develop knowledge products should be carried out. Sites to be considered include Malosa montane grassland, Mangochi Mountain montane evergreen forest, Mangochi valley grassland with *Protea,* and a site on the dry northern escarpment in the Malosa FR that lies in the Chingale catchment.

Focused zoological studies should be conducted at a limited number of priority sites. The goal would be to identify species that were indicator species of more general ecosystem health and function, and/or "flagship" species that could be used to motivate conservation actions in the area where they are found, and/or themselves "keystone" species, influential in structuring the natural habitat in which they were found (e.g., elephants). We conducted a desk review of the current state of zoological information for the five areas that had either high regeneration potential sites or high levels of globally-rare, restricted range species according to the analysis of RBS survey data. This focused mainly on birds, large mammals, butterflies, reptiles and amphibians, small mammals including bats, and other insects. Limitations of Year 2 resources will probably limit these studies to a few of the highest priority site-by-taxon studies.

Valuation studies for environmental services and products should be conducted. Modelling will be used to estimate the economic values for hydrological services at the five Year 2 priority areas. These values include the values of water captured by those areas for domestic supply, hydropower, and irrigation; the value of flow stabilization from forest cover in preventing flooding; the value of soil retention and sediment reduction to downstream users; and the value of water for environmental flows in downstream areas of importance to biodiversity, including Elephant Marsh. Estimated economic and livelihood values for ecosystem products from one or more of the Year 2 priority sites to local communities will be determined by desk and field study. Products of potential value include firewood, charcoal, poles, thatching grass, bamboo, reeds, mushrooms, wild fruits, medicinal plants, bushmeat, and edible insects.

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Acronyms

BRAHMS	Botanical Research and Herbarium Management System
DECORANA	Detrended Correspondence Analysis
DF	Department of Forestry, Malawi
DNPW	Department of National Parks and Wildlife, Malawi
DoS	Department of Surveys
FR	Forest Reserve
FRIM	Forest Research Institute of Malawi
GEF	Global Environment Facility
GHI	Genetic Heat Index
GIS	Geographical Information System
ICRAF	World Agroforestry Centre
IUCN	International Union for Conservation of Nature
MASDAP	Malawi Spatial Data Portal
M&E	Monitoring and Evaluation
MCE	Multi-Criteria Evaluation
MoM	Museums of Malawi
MOMS	Management Oriented Monitoring System
MWDI	Ministry of Water Development and Irrigation
NHBG	National Herbarium and Botanic Gardens of Malawi
NP	National Park
NRM	Natural Resource Management
PAD	Project Appraisal Document
PDO	Program Development Document
RBS	Rapid Botanic Survey
SLWM	Sustainable Land and Water Management
SRBMP	Shire River Basin Management Program
ToR	Terms of Reference
WR	Wildlife Reserve

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1. Background

The "Strengthening the Information Base of Natural Habitats, Biodiversity and Environmental Services in the Shire Basin" is a component of the Shire River Basin Management Program. We will hereafter refer to this component of the SRBMP as the *Natural Habitats Surveys* activity, a phrase that succinctly describes the main themes of our work.

The overall objective of the Natural Habitat Surveys activity is to establish a comprehensive, up-to-date and high quality inventory of the status of natural ecosystems and species in the Shire River Basin, and to improve information about the value of the ecosystem products and services they provide. This information will be made available in a range of communication formats suitable for informing resource planning and management at the basin level and at key biodiversity sites.

Another important objective of the activity is to foster capacity-building, knowledge exchange, and partnership development with key institutions in Malawi that are concerned with the management of natural habitats and species, including the Forest Research Institute of Malawi, the National Herbarium and Botanic Gardens, and the Department of National Parks and Wildlife.

As indicated in the long title of this activity, it is concerned with three types of information:

1) *Natural habitats*: these are natural ecosystems (e.g., forests, woodlands); ecosystem diversity is one level of biodiversity.
2) *Biodiversity*: Biodiversity is the diversity of life at three levels: genetic diversity within species, species diversity within ecosystems, and ecosystem diversity within the biosphere.
3) *Environmental services*: Environmental or ecosystem services are the benefits provided to people from ecological functions and processes resulting from the biodiversity that makes up natural habitats. Examples of ecosystem services include: hydrological services of stable flows of clean water from forests and wetlands, including flood risk reduction and mitigation; erosion control and soil retention; pollination services of wild pollinators; soil nutrient cycling; and pest and pathogen control (e.g. reduction of insect pests by birds and bats).

The wider context and purpose for strengthening the information base about natural habitats, biodiversity, and environmental services that the Natural Habitats Surveys component will support is to:

- inform management decision making;
- increase awareness of the value of natural ecosystems and species within local communities;
- improve collaboration among local communities and the government agencies responsible for natural resources management, in order to improve the conservation and sustainable use of natural habitats and species; and
- enhance the information available to natural resource users and managers in the Shire River Basin.

The Program Development Objective (PDO) of the SRBMP, as given in the Project Appraisal Document (PAD) (p. vii), is to: Increase sustainable social, economic and environmental benefits by effectively and collaboratively planning, developing and managing the Shire River Basin's natural resources. The first phase project would establish coordinated inter-sectoral development planning and coordination mechanisms, undertake the most urgent water related infrastructure investments, prepare additional infrastructure investments, and develop up-scalable systems and methods to rehabilitate sub-catchments and protect existing natural forests, wetlands and biodiversity.

The Natural Habitats Surveys activity feeds information into Sub-component A.1: ***Develop a Shire Basin Planning Framework***, which will "support the development of a structured knowledge base for the Shire Basin and associated knowledge products (hardcopy and interactive), including a Shire River Basin Atlas, a Shire State of the Basin Report, and other spatial analysis products (including technical and interpretive biodiversity and ecosystem knowledge products). The knowledge base would be strengthened through collation of existing data and information products, as well as through support for new surveys and mapping (e.g. of water resources, natural habitats, biodiversity, satellite imagery acquisition…" (SRBMP PAD, p. 8)

The Natural Habitat Surveys activity also supports Component B: ***Catchment Management***, and in particular Sub-component B.2: ***Rehabilitate Targeted Catchments***. Activities for the rehabilitation of four targeted, high-priority catchments "will finance interventions identified in micro-catchment plans prepared under sub-component B.l, including: (i) soil and water conservation for more sustainable and productive agriculture; (ii) forestry and rural energy interventions to restore forest cover and reduce firewood consumption within the sub-catchments; (iii) stream and water control, including check dams and small earthen dams to support improved water management through smaller-scale structures built by community members." (SRBMP PAD, pp. 11-12) Because natural ecosystems provide eco-hydrological services within catchments, information developed through Natural Habitat Surveys will inform Sub-component B.2.

The Natural Habitat Surveys activity is closely linked with SRBMP Sub-component B.4: **Improve Ecological Management** which is described in the SRBMP PAD as follows: "Incremental GEF support will provide for strengthened management of large natural habitat blocks within the Shire Basin, including: (i) selected infrastructure and capacity investments in Lengwe and Liwonde National Parks to increase their long-term revenue flows; (ii) implementation of community forest co-management in the Neno Eastern Escarpment and Tsamba Forest Reserves in Neno district, which will complement the IDA-funded SLWM investments under sub-component B.2 to form part of an integrated landscape management approach; and (iii) zoning, patrolling and monitoring of the Mangochi Forest Reserve adjacent to the Liwonde National Park, in recognition of the key importance of these forests as a wildlife corridor." (SRBMP PAD, p. 12) Natural Habitat Surveys fits here, but is only a part of this sub-component, specifically aimed at the information on natural habitats, species, and ecosystem services needed for improved management of remaining natural habitats in the Shire River Basin.

Within the SRBMP monitoring and evaluation (M&E) system, the PDO-level results indicator most related to the Natural Habitat Surveys activity is "Vegetation cover change as a percentage of baseline in selected catchments." (SRBMP PAD, page A-2) This indicator is supposed to be based on changes in agricultural land, as well as forest land and protected areas, "in targeted areas" (i.e., the four Priority Catchments of Component B).

2. Activities, Approaches and Methods

2.1 Year 1 Timeline of Activities

Activities undertaken during Year 1 were sequenced as described in the Inception Report, according to the timeline shown below.

- Inception mission (16-21 March 2015)
- Inception Report (accepted August 2015, following incorporation of comments on drafts)
- The assessment of existing available data
- Site selection workshop and rapid botanic surveys (RBS) training (1-5 June 2015)
- Natural habitats surveys using RBS methodology (June-August 2015)
- Data entry and analysis (Sept-Oct 2015)
- Presentation of Year 1 Results and Year 2 Work Planning (16-20 November 2015)
- Submission of spatial data and related information for SRB Atlas and Portal (4 December 2015)
- Year 1 Analytical Report (1 February 2016)

2.1.1 Assessment of existing data

The assessment of existing data included detailed physical library searches at research, academic, museum and public offices throughout Malawi as well as internet based literature review. Existing biodiversity and natural habitat information was limited to certain well studied areas (e.g. Liwonde National Parks) or was historical in nature (often over 20 years old). Information was often lacking relevant metadata (e.g. detail on locations of sample sites or sampling methods used for sample data collection) making its utility and generalisability very limited.

Available spatial and map data was gathered from government offices and research institutions throughout Malawi. Much was limited in spatial extent (e.g. related to only specific project areas or attributes of interest) but a number of national data sets were identified (detailed in the Inception Report). These were used in the spatial modelling and analysis undertaken and presented in this report.

2.1.2 Deliverables

The following deliverables were completed as part of the Year 1 programme of activities:

- Inception Report
- Submission of spatial data on natural habitats for Shire River Basin Portal and Atlas (Natural Habitat maps and Forest Cover Maps) covering Shire River Basin and 12 protected areas
- Natural Habitats Survey Reports (Botanical) for 12 protected areas and areas outside of protected areas (incorporated as Annex C of this Year 1 Analytical Report)
- Biodiversity inventory (botanical) for 12 surveyed areas (incorporated as Annex D of this Year 1 Analytical Report)
- Training of FRIM & NHBG staff on Rapid Botanical Survey and BRAHMS data entry.

2.2 Selecting Sites for Field Surveys

The initial areas for our attention in this component were listed in the Terms of Reference (date of 30 November 2013): "The focus of this consultancy is to conduct studies on natural ecosystems, habitats, and biodiversity in the Shire Basin including Mangochi, Tsamba and Eastern Escarpment forest reserves, Elephant Marsh, Lengwe and Liwonde National Parks so that the overall knowledge and understanding of natural habitats, biodiversity and ecosystems in the Shire river basin is enhanced." Because the specific places listed were protected areas or other large areas, we began to call these areas "sites." In addition to these protected areas, our Terms of Reference also require us to consider rapid surveys in:

- at least four "other remnant forest areas" and any other areas of significant natural vegetation/forest that we can find on satellite imagery;
- "ecological corridors where improved sustainable forest management could improve ecological inter-linkages within the basin"; and
- areas within the four Priority Catchments under Sub-components B1 and B2 could benefit from catchment planning and restoration to help restore ecological linkages and ecosystem services.

At the Inception Workshop in Zomba in March 2015, the "sites" for our surveys and studies were discussed. Elephant Marsh was removed from the list because it became the focus of another consultancy. Three additional forest reserves were added to the list: Liwonde, Zomba-Malosa, and Matandwe. Thus, after the Inception Mission, the list of sites we were to consider stood at eight, including Mangochi FR, Tsamba FR, Neno East Escarpment (proposed FR), Liwonde FR, Zomba-Malosa FR, Matandwe FR, and Lengwe and Liwonde NPs, plus possible other areas of significant remnant forest. A multi-stakeholder consultative process to prioritize and select the areas in which to conduct detailed plant field surveys and collections was applied in June 2015. Given time and resource limitations, a full inventory was not possible; instead, the detailed botanical sampling described below was conducted at representative sample sites within each of the larger areas.

At the Site Selection and Rapid Botanic Surveys Training Workshop, sites were selected by a working group of Natural Habitats Surveys team members, international consultants, and staff of FRIM and NHBG who have worked extensively in the Shire Basin. A site-selection matrix was used along with high resolution, up-to-date satellite imagery of the Shire River Basin (Google My Maps:
https://www.google.com/maps/d/edit?mid=z9MpPiI5gYf4.kScnYcoZ61NA&usp=sharing)

Visual inspection of the satellite imagery, combined with local knowledge, allowed for selection of sites based on the prioritization criteria. The following areas were initially considered: Mangochi FR, Tsamba FR, Neno East Escarpment (proposed FR), Liwonde FR, Zomba-Malosa FR, Matandwe FR, Lengwe NP, Liwonde NP, Chingale catchment, Kapichira catchment, Lisungwi catchment, Upper Wamkulumadzi catchment, Thambani FR, Matandwe FR, Mwabvi WR, and "sites known to harbour important biodiversity in Thyolo" (these were forest patches on private tea estate land).

Criteria for site selection included whether a site:

- Is located in a protected area (e.g., forest reserve, national park)
- Is outside of a protected area but with significant natural vegetation
- Already has a strong information base on vegetation status and/or species
- Has potential as an ecological corridor
- Is within a SRBMP priority catchment
- Is relevant to resource planning and management at basin level

After the field-based training in the rapid botanic survey (RBS) methodology (see Section 2.3 below), it was realised that with the time and staff available, we could collect plant samples at several plots or "sampling sites" in 12 different areas (an area being a particular Forest Reserve or National Park, for example).

By the end of our fieldwork at the end of August 2015, our teams were able to conduct detailed surveys of plants in 12 areas, each sampled at 2-7 sites (see Table 2.1 below), for a total of 52 sampled sites. This greatly exceeded our initial sampling proposal outlined in the Inception Report.

2.3 Rapid Botanic Survey Methodology

The Rapid Botanic Survey (RBS) methodology we used was developed by Dr. William Hawthorne, Plant Sciences Department, University of Oxford (Hawthorne and Marshall, 2015). The RBS manual describes RBS "primarily a field survey methodology but [it] is associated with a range of non-field activities, analyses and outputs that can be considered part of RBS in the broad sense". The RBS methodology allows a high percentage of all plant species occurring at a sample site to be collected very rapidly, especially when compared to traditional herbarium collections. The flowchart in Figure 2.1 summarises the overall process – from choice of sites to data entry and analysis. RBS uses a number of standard botanical and ecological techniques and approaches as part of the process, but also differs from classic forestry or ecological surveys, in particular in its use of plot-less sampling.

All species, or as many as can be found in a half day, are recorded in defined habitats, with the majority of records vouchered. RBS samples are generally collected from an area that is unmeasured and "plot-less," based around a central point that is within a patch of vegetation that represents a recognisable condition within the spectrum of local vegetation and landscape conditions. As many species as possible are collected rapidly, representing a highly representative majority, at least, of all species present in that vegetation community. Ideally, collecting and recording continues until no more species can be found easily in the defined area (Hawthorne and Marshall, 2015).

The larger ("canopy") trees at each sampling site are assessed as a count of all trees above a set minimum diameter threshold, which can be set at 30, 20, 10, or even 5 cm diameter at breast height (DBH). Trees ≥30 cm are first counted, and if fewer than 40 trees of that minimum diameter are found in the sample site, successively lower thresholds are accepted until 40 trees had been counted – unless that habitat did not contain that many trees.

Following field collection, specimens are pressed and dried, and subsequently sorted into families and identified. Species determinations are merged with the field records.

Choice of RBS field sites

- Using various criteria, areas (for example, a particular Forest Reserve or National Park) were identified as a priority for botanical sampling using RBS method
- High resolution, up-to-date spatial imagery of the Shire River Basin was used to identify sites of natural vegetation within these area. These areas were then targetted by field teams on the ground

Fieldwork and sample collection

- Find site of defined, homogenous vegetation for sampling - not restricted to a defined plot size or shape - ideally containing at least 40 trees of dbh ≥30cm
- Collect vouchers of almost all species present within this site, and identify at least 40 trees, working outwards from a central point
- Samples initially identified in the field
- Ethnobotanical information and observations on habitat use and threats observed also recorded

Sample processing

- Plant vouchers dried using efficient fan driers and aluminium corrugates overnight after fieldwork
- Vouchers organised into family groups and stored in "bundles"
- Final determination, using herbarium collections for verification, is carried out systematically by family group

Data entry and analysis

- BRAHMS database primed - including a full list of species known to occur in Malawi
- Field data entered into BRAHMS
- Final determinations of vouchers entered into BRAHMS - use of online plant databases to ensure accepted names, and not synonyms, used and quality checked using photographs of specimens
- Analysis: ordination and classification of survey data by sample site; assessment of regeneration potential and presence of globally-rare species

Figure 2.1 Flow diagram summarising the RBS process – from sample site selection to data analysis

Natural Habitats Surveys plant sampling team in the field.

Photo credit: LTS/D. Mauambeta

Natural Habitats Surveys plant sampling team in the field.

Photo credit: LTS/ B. Byers

Analysis of plant samples can be used for mapping vegetation and prioritising areas for different management purposes. RBS methods integrate species and community-level assessments of plant biodiversity, and RBS data are used to determine the main patterns of floristic variation across a landscape. RBS builds on a foundation of herbarium data and provides a generally more complete and less biased picture of plant biogeography and ecology than available from herbaria alone. New samples collected using the RBS methodology often fill gaps in knowledge about plant distribution, and provide data on a variety of natural habitats in a defined survey area, using a standardized approached (Hawthorne and Marshall, 2015).

Two days of hands-on training and practice using RBS methodology with field team members and international experts, including sample processing and species identification, were conducted in the Liwonde and Zomba-Malosa Forest Reserves in June 2015. It quickly became apparent from understanding and practicing the RBS field collection methodology that although these were called "rapid botanic surveys" because they require only approximately one-half day to sample at a given location, they were also detailed surveys of plant biodiversity, and not at all preliminary or superficial surveys.

2.4 Field Sampling

Botanical field surveys were undertaken by field teams of four to six persons. Each team had a team leader supplied by the Natural Habitats Surveys contractor (LTS International and CDM) and staff from the NGBG and FRIM. Field surveys sampled vegetation at 52 locations in 12 protected areas and other areas of significant natural vegetation throughout the Shire Basin between June-August 2015. Specimens were processed and identified at the National Herbarium and Botanic Gardens in Zomba. Plant data were entered into a botanical database, the Botanical Research and Herbarium Management System (BRAHMS), which enabled detailed statistical analysis of vegetation composition and other characteristics.

The following steps were generally followed by the field surveys teams:

- The District Forestry Office and local community members were contacted and involved;
- Sampling sites were identified upon arrival at pre-selected area;
- The field team collected, vouchered, and makes preliminary identifications of all plant species that could be found at the sampling site;
- Trees larger than a pre-determined minimum size (usually 30 cm DBH) were counted and mapped using GPS tracks at the site;
- Ethnobotanical information was collected through discussion with community members;
- Photographs were taken and GPS reference points recorded;
- Specimens collected during the day were dried overnight;
- Final species determinations were made upon return to Zomba using the National Herbarium collection for reference material;
- Plant data were entered into the BRAHMS database;
- A quality check of species identifications was made via photographs sent to Dr. William Hawthorne.

Figure 2.2 Map of areas in which botanical surveys were conducted.

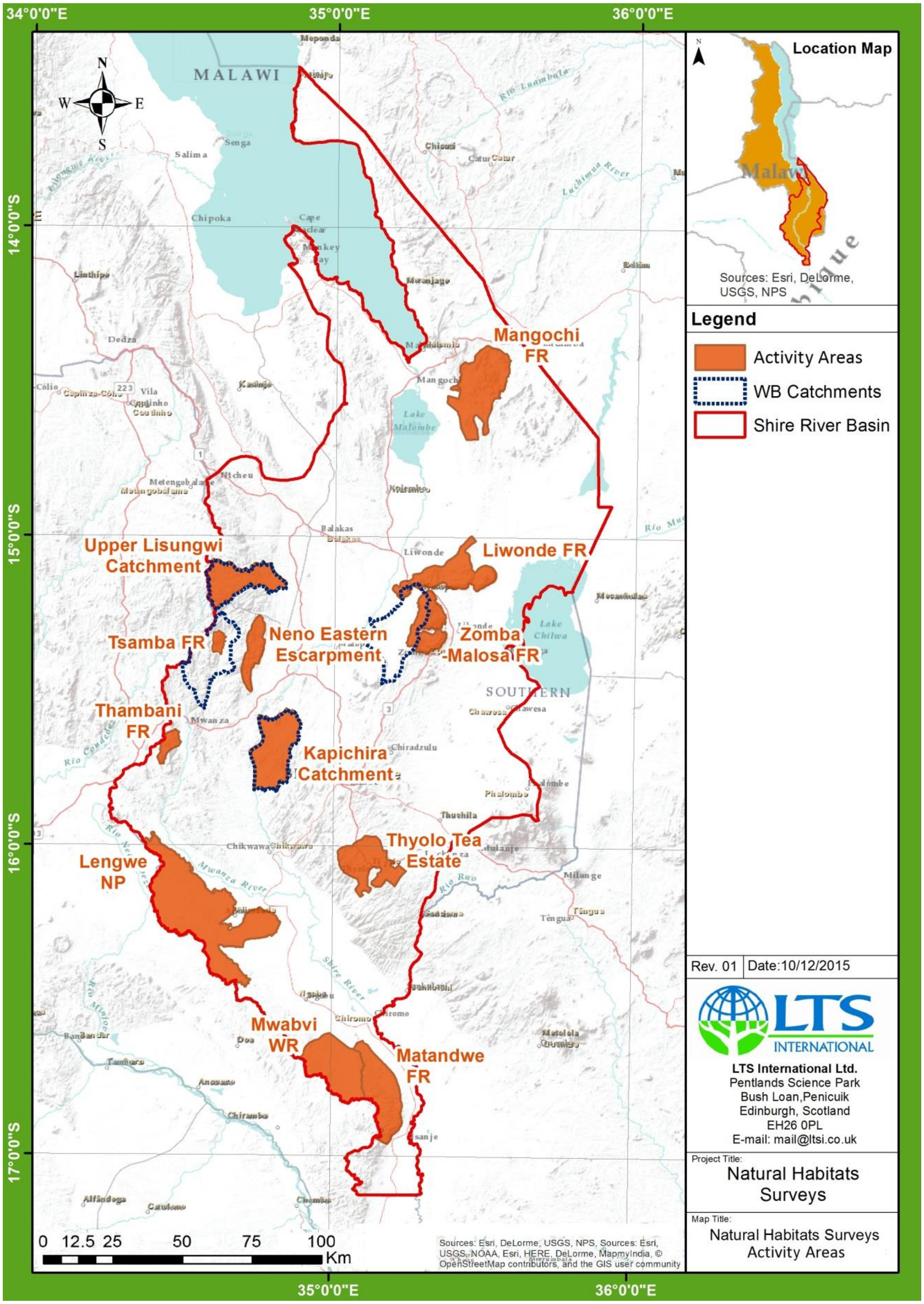


Table 2.1 Botanic surveys: areas, sample plots, specimens collected.

Surveyed Area	Number of sample plots	Total number of plant specimens collected
Mangochi Forest Reserve	6	549
Liwonde Forest Reserve	7	491
Zomba-Malosa Forest Reserve, including overlap with Chingale Catchment	7	446
Upper Lisungwi Catchment	3	258
Neno East Escarpment	6	378
Thyolo Tea Estates	4	463
Tsamba Forest Reserve, within Upper Wamkulumadzi Catchment	4	416
Thambani Forest Reserve	4	367
Kapichira Catchment	2	152
Lengwe National Park	4	295
Matandwe Forest Reserve	3	269
Mwabvi Wildlife Reserve	2	87
Total	52	4171

A large number of photographs were taken during the field surveys, providing strong photo documentation of the vegetation at each site, and its condition. Approximately 4,700 photographs were taken. The archive of these photos will be very valuable for visually detecting vegetation change at the sites through re-photography.

2.5 Analysis of Plant Samples

Because the botanical information from the Year 1 RBS plant surveys was entered into the BRAHMS database, various kinds of statistical analyses are possible. For example, such analyses allow an empirical process of vegetation classification, an assessment of the condition of the vegetation at a site based on the presence and abundance of canopy tree species, and an assessment of the presence of globally-rare, restricted range species. Such information can support the objectives of the Natural Habitats Surveys activity by providing up-to-date and high quality information that can inform management decision-making in the Shire River Basin.

2.6 Mapping Methodologies

One category of results produced by the Natural Habitats Surveys component of the SRBMP during Year 1 is based on geospatial analysis, modelling, and mapping. Methodologies underlying the production of these maps are outlined here, with the maps themselves presented in Section 3 – Results.

2.6.1 General mapping methodology

The Python window, to execute geoprocessing commands and script within ArcMap, was used to produce all the map outputs. This script was set up to zoom and clip all layers to be exported to the individual Areas and export all the layers that were loaded and manually styled and designed for visualization within the workspace. The map titles were derived from the layer names for each map and the process was iteratively carried out for each individual Sampled Site within the activity, exporting both a 300dpi .png and .jpeg image for use in the reports and other submissions.

2.6.2 Potential Natural Vegetation

The map of the potential natural vegetation of the Shire Basin shown in Fig. 3.1 is derived from a regional map covering eastern Africa (Van Breugel, et al., 2015). That larger map gives the distribution of potential natural vegetation in the wider Eastern African Region, which distinguishes 48 vegetation types, divided in four main vegetation groups: 16 forest types, 15 woodland and wooded grassland types, 5 bush land and thicket types, and 12 other types of vegetation. 21 types of potential natural vegetation would be represented in the Shire River Basin in the absence of human influences. The area that would be occupied by each of these potential natural vegetation types is given in Table 3.1.

2.6.1 Land Cover and Land Use 2015 and Forest and Woodland Area 2015

Natural Forest Areas were derived from the land cover maps for 2015. The land cover maps for 2015 have been created using Landsat optical data, pre-processed and mosaicked to cover the Shire Basin, at 30m resolution. Suitable data were chosen to adhere to UNFCCC Good Practice Guide (IPCC, 2003) as closely as possible, with the same type of satellite imagery (spatial resolution, spectral channels and year, season and time) which is recommended and can be used to carry out a comparison in land cover/use change over time. Season was an important factor for avoiding large areas of cloud cover during the rainy season, between around November - April.

The Landsat layers for the region were then converted to land cover map through an Iso Cluster unsupervised classification approach (Richards, 1986) to identify broad categories of land cover. The classification breakdown used is based on that recommended for land user classification in accordance with the UNFCCC Good Practice Guide (IPCC, 2003) and Guidelines for Agriculture, Land Use and Forestry (IPCC, 2006), which uses the six classes: Forest land, Cropland, Grassland, Settlements, Wetlands, and Other land. The classifications were then broken down into more detailed land cover and use categories, backed by ground-truthing, expert interpretation and through the use of other high resolution optical imagery and Google map layers to verify and classify the land cover. Details of forest types were then extrapolated by the potential natural vegetation index (Kindt et al., 2011) and attributed to the forest land data in the land cover layer. The forest areas, excluding forest plantations, were extrapolated from this to create the Natural Forest area layer.

2.6.2 Risk of Natural Habitat and Forest Degradation from Human Activities

The model to determine the potential threat of anthropogenic impacts on natural forest areas was applied to the Natural Forest Area boundary layer, derived from the 2015 land cover mapping work. The model takes into account key drivers of deforestation and degradation in the form of accessibility to forest resource and markets, demand of forest products via population, and risk of conversion of forested areas to cropland. This model is not comprehensive but looks at data from 2015 to gain insight into areas that may be at higher risk of deforestation and degradation relative to one another, with the idea that more data and improvements will be made as the work under SRBMP continues.

Accessibility to the forest resource and to areas where forest products are sold and consumed is determined by distance from road, distance from markets as well as distance from settlement areas, with areas closest to these layers being at higher risk. Road and markets data layers are derived from data obtained through the Department of Surveys (DoS), within the Malawi Government, and the inclusion of up to date OpenStreet Map data layers, created through a series of community mapping programs and crowd sourcing activities. The settlement areas are derived from the 2015 land cover mapping work and include all areas of settlement found, however large or small. Population density was derived from 2008 census data which was extrapolated to 2015 based on World Bank population growth rate figures and determined the demand for forest products. Maize suitability layer, obtained from digitising the findings from the 1991 Land Resources Evaluation Project-Malawi, was also included to look at the likelihood of conversion from forest area to cropland within the Shire Basin with the assumption that likelihood would be related to suitability.

The layers, after being reclassified and standardised to fit the model, were combined through a multi-criteria evaluation (MCE) with quantitative criteria being evaluated as fully continuous variables to give an overall picture of the anthropogenic threat risk to natural forest areas with the Shire Basin.

3. Results

3.1 Results from Geospatial Analysis, Modelling, and Mapping

3.1.1 Potential Natural Vegetation

Fig. 3.1 shows the 21 types of potential natural vegetation that would be represented in the Shire River Basin in the absence of human influences, and table 3.1 includes a breakdown of the area of the Shire Basin by habitat type.

This can be compared with the next map which shows the actual land use and vegetation cover using up-to-date spatial imagery, and as a result shows the influence of human activities. Different land use classes are therefore present in the Land Cover and Land Use 2015, such as cultivated land and settlements. A bar chart comparison of the differences between these maps is included in Annex G.

Fig. 3.1 Potential Natural Vegetation in the Shire River Basin

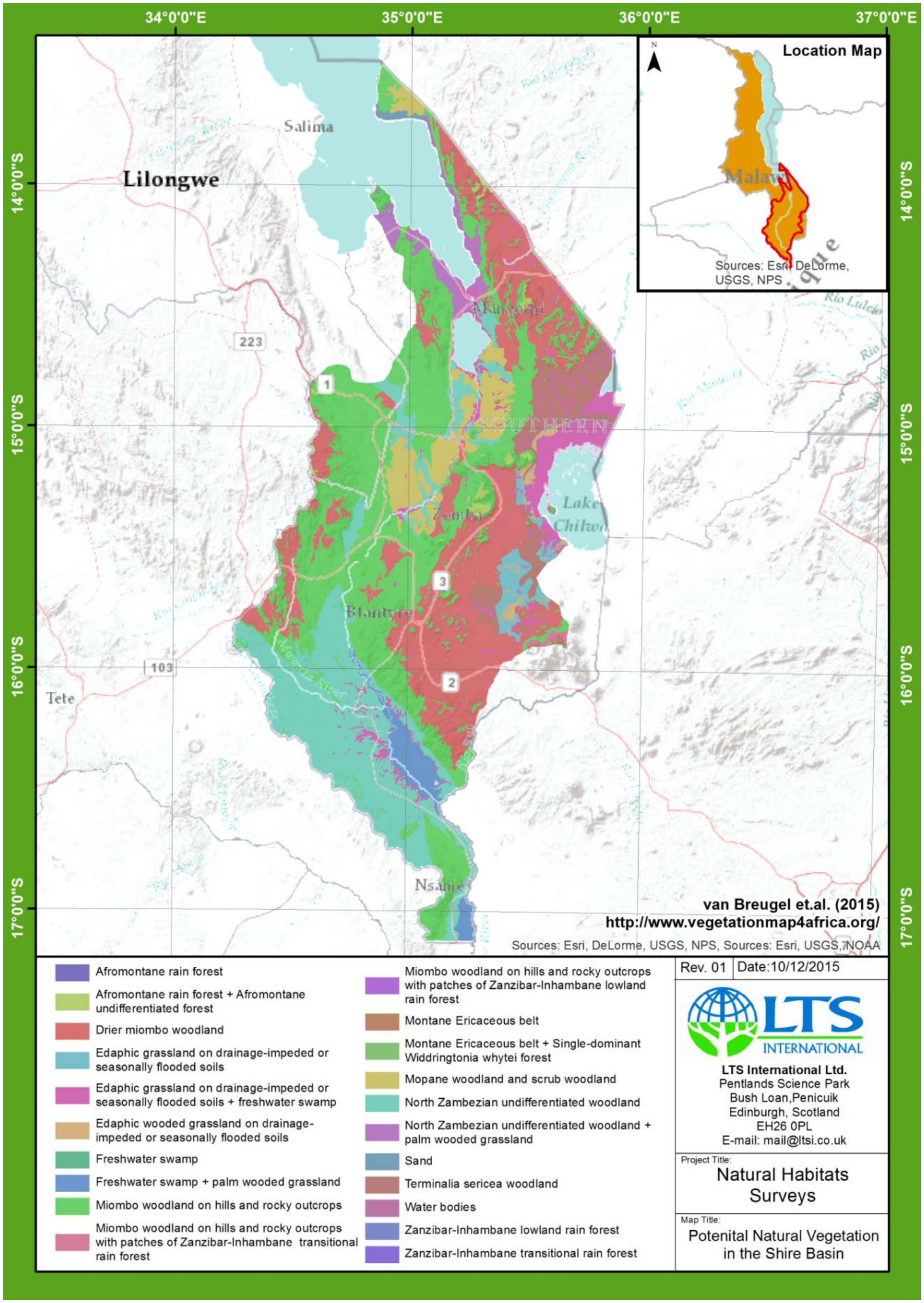


Table 3.1 – Potential Natural Vegetation area (ha) by type, Shire River Basin.

Potential Natural Vegetation	Area (ha)	Approx. percentage cover
Afromontane rain forest	9.7	<0.1%
Afromontane rain forest + Afromontane undifferentiated forest	19,312.4	0.6%
Drier miombo woodland	733,408.0	24.0%
Edaphic grassland on drainage-impeded or seasonally flooded soils	50,923.8	1.7%
Edaphic grassland on drainage-impeded or seasonally flooded soils + freshwater swamp	191,105.0	5.3%
Edaphic wooded grassland on drainage-impeded or seasonally flooded soils	18,984.2	0.6%
Freshwater swamp	23.8	<0.1%
Freshwater swamp + palm wooded grassland	71,386.5	2.3%
Miombo woodland on hills and rocky outcrops	1,033,060.0	33.8%
Miombo woodland on hills and rocky outcrops with patches of Zanzibar-Inhambane transitional rain forest	5,914.0	0.2%
Miombo woodland on hills and rocky outcrops with patches of Zanzibar-Inhambane lowland rain forest	31.3	<0.1%
Montane Ericaceous belt	1,795.1	<0.1%
Montane Ericaceous belt + Single-dominant Widdringtonia whytei forest	587.4	<0.1%
Mopane woodland and scrub woodland	154,761.0	5.1%
North Zambezian undifferentiated woodland	530,372.0	17.4%
North Zambezian undifferentiated woodland + palm wooded grassland	59,209.6	1.9%
Sand	6,571.7	<0.1%
Terminalia sericea woodland	132,341.0	4.3%
Water bodies	43,232.1	1.4%
Zanzibar-Inhambane lowland rain forest	0.6	<0.1%
Zanzibar-Inhambane transitional rain forest	5.2	<0.1%
TOTAL	**3,053,034.4**	

3.1.2 Land Cover and Land Use 2015

Fig. 3.2 shows a map of land cover and land use in the Shire Basin, created using up-to-date spatial imagery. Section 2.6.1 describes the methodology fully. Table 3.2 includes a breakdown of the area of the Shire Basin by habitat type.

Fig. 3.2 Land Cover and Land Use 2015 in the Shire River Basin

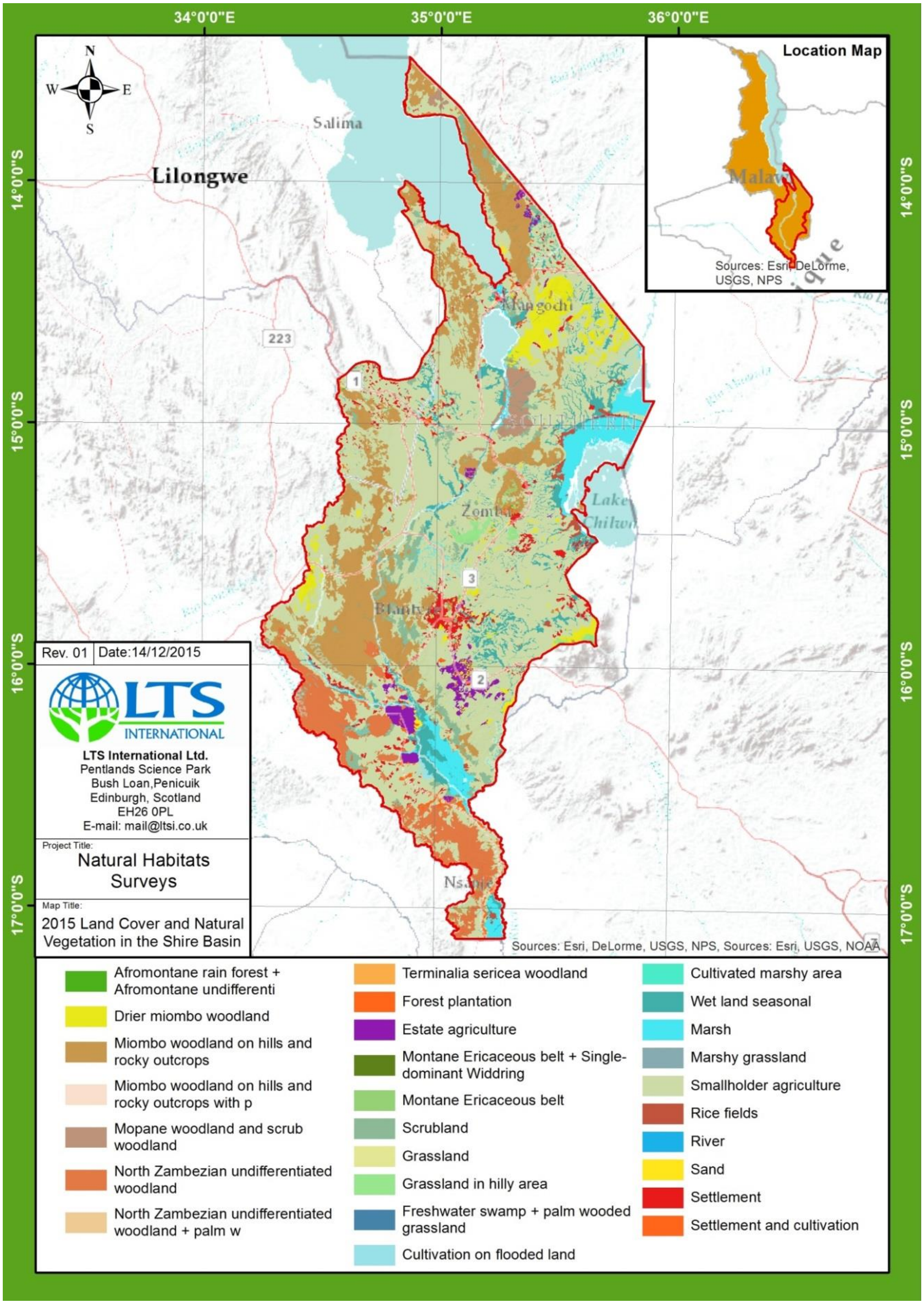


Table 3.2 Land cover/land use area (ha) by type, Shire River Basin

Land Classification	Area (ha)	Approx. percentage cover
Afromontane rain forest + Afromontane undifferentiated forest	429.1	<0.1%
Cultivated marshy area	209.5	<0.1%
Cultivation on flooded land	11,621.6	0.4%
Drier miombo woodland	107,036.7	3.5%
Estate agriculture	45,241.1	1.5%
Forest plantation	3,870.3	0.1%
Freshwater swamp + palm wooded grassland	96.6	<0.1%
Grassland	2,380.2	<0.1%
Grassland in hilly area	19,613.6	0.6%
Marsh	133,386.2	4.4%
Marshy grassland	107.9	<0.1%
Miombo woodland on hills and rocky outcrops	487,276.8	15.9%
Miombo woodland on hills and rocky outcrops with patches of Zanzibar-Inhambane transitional rain forest	47.1	<0.1%
Montane Ericaceous belt	161.6	<0.1%
Montane Ericaceous belt + Single-dominant Widdringtonia whytei forest	129.1	<0.1%
Mopane woodland and scrub woodland	40,159.8	1.3%
North Zambezian undifferentiated woodland	178,054.9	5.8%
North Zambezian undifferentiated woodland + palm wooded grassland	6498.0	0.2%
Rice fields	15,560.6	0.5%
River	8,327.0	0.3%
Sand	2450.1	<0.1%
Scrubland	103,712.0	3.4%
Settlement	77,872.1	2.5%
Settlement and cultivation	20,675.3	0.7%
Smallholder agriculture	1,560,882.0	51.1%
Terminalia sericea woodland	39.7	<0.1%
Water surface	66,515.3	2.2%
Wet land seasonal	160,681.6	5.3%
TOTAL	**3,053,035.6**	

3.1.3 Forest and Woodland Area 2015

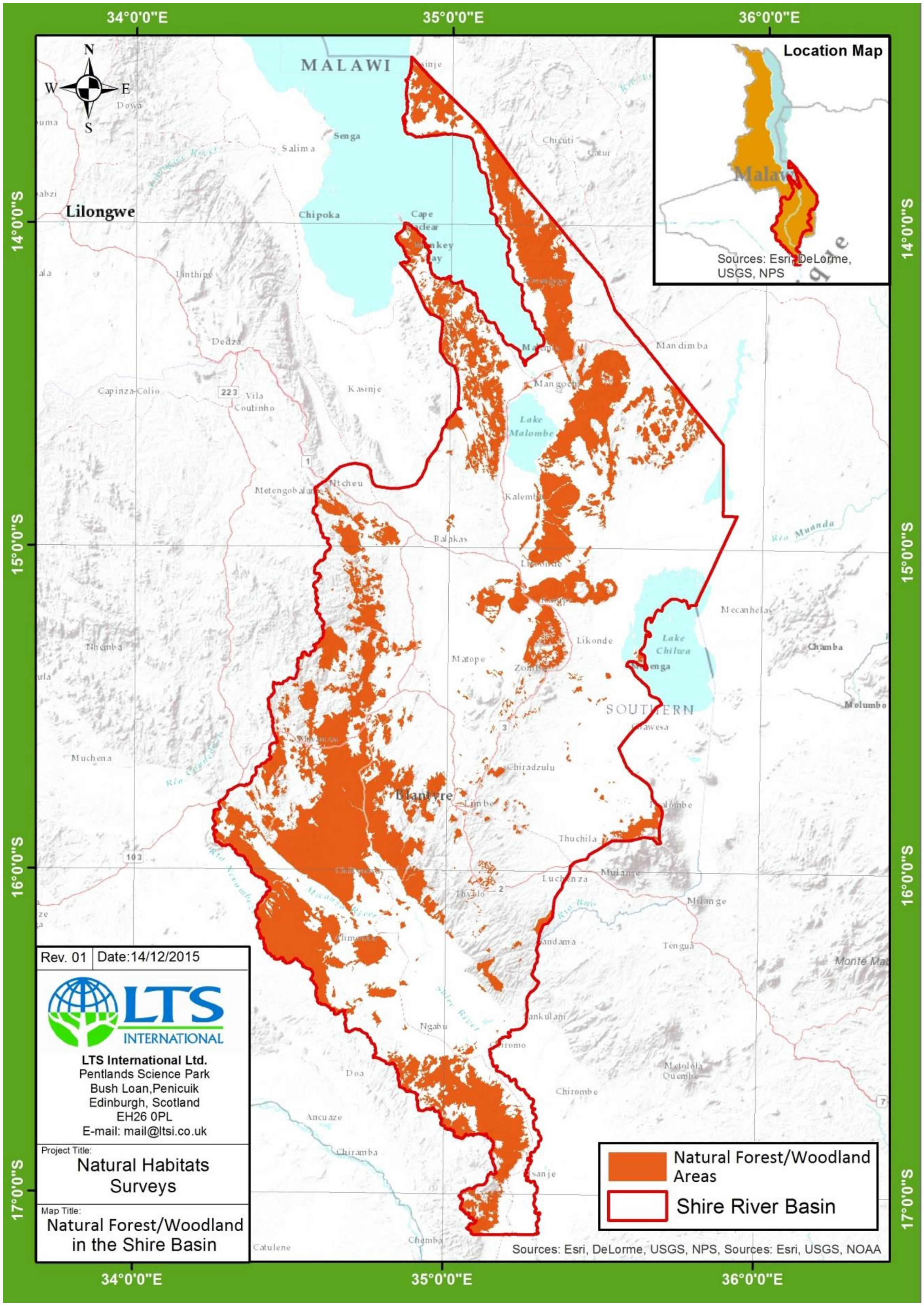
Areas of natural forest and woodland were derived from the overall land cover/land use map for the Shire Basin (see Fig. 3.2 above) – the area of natural forest and woodland in 2015 is shown in Fig. 3.3.

Forest and woodland areas, excluding forest plantations, were then mapped, and areas calculated (Table 3.3).

Table 3.3 Natural forest area (ha) by type, Shire River Basin

Forest/Woodland Type	Area (ha)
Afromontane rain forest + Afromontane undifferentiated forest	429.1
Drier miombo woodland	107,036.7
Miombo woodland on hills and rocky outcrops	487,276.8
Miombo woodland on hills and rocky outcrops with patches of Zanzibar-Inhambane lowland rain forest	47.1
Montane Ericaceous belt	161.6
Montane Ericaceous belt + Single-dominant Widdringtonia whytei forest	129.1
Mopane woodland and scrub woodland	40159.8
North Zambezian undifferentiated woodland	178,054.9
North Zambezian undifferentiated woodland + palm wooded grassland	6498.0
Total area of forest/woodland in the Shire Basin	819,793.0

Fig. 3.3 Natural Forest and Woodland 2015 in the Shire River Basin



3.1.4 Risk of Natural Habitat and Forest Degradation from Human Activities

Fig. 3.4 and 3.5 illustrate the threat to natural habitat degradation as a result of human activities. They are both derived using a model described more fully in section 2.6.2. A computer-based model that takes into account the key human threats to forests was applied to the areas of natural forest (see Fig. 3.3 above) derived from 2015 Landsat data. Human threats were modelled based on geospatial data, including distance from roads, distance from markets, distance from settlements, population density, and suitability for maize production. The model assumes causal relationships between these factors and deforestation and forest degradation. The model also assumed that the likelihood of forest conversion was related to suitability for maize cropping.

This model is not comprehensive but uses data from 2015 to predict areas that may be at higher risk of deforestation and forest degradation. This information can then be used to prioritize areas of focus for forest conservation and management.

Fig. 3.4 Anthropogenic Threats to Natural Habitats in the Shire River Basin

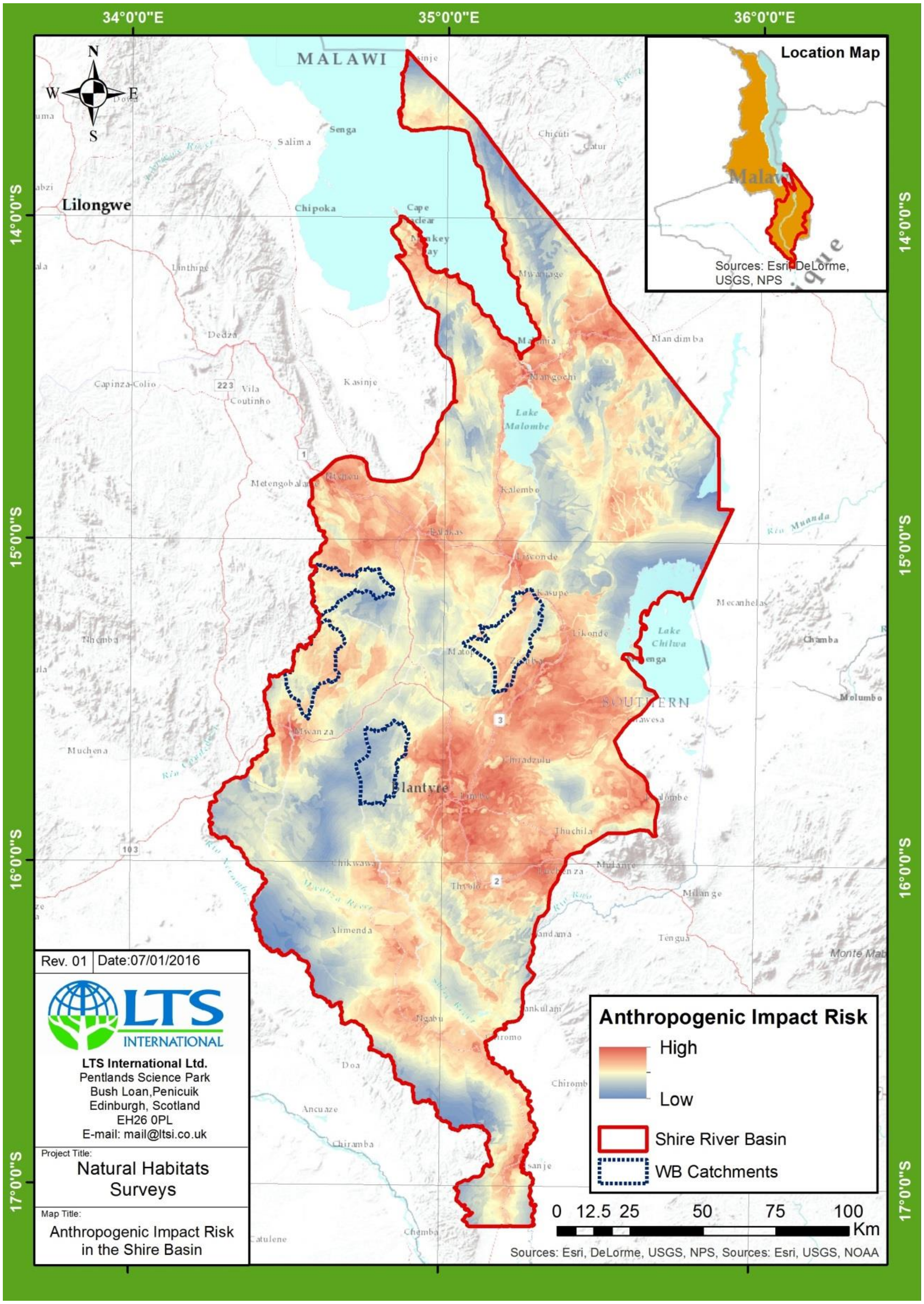
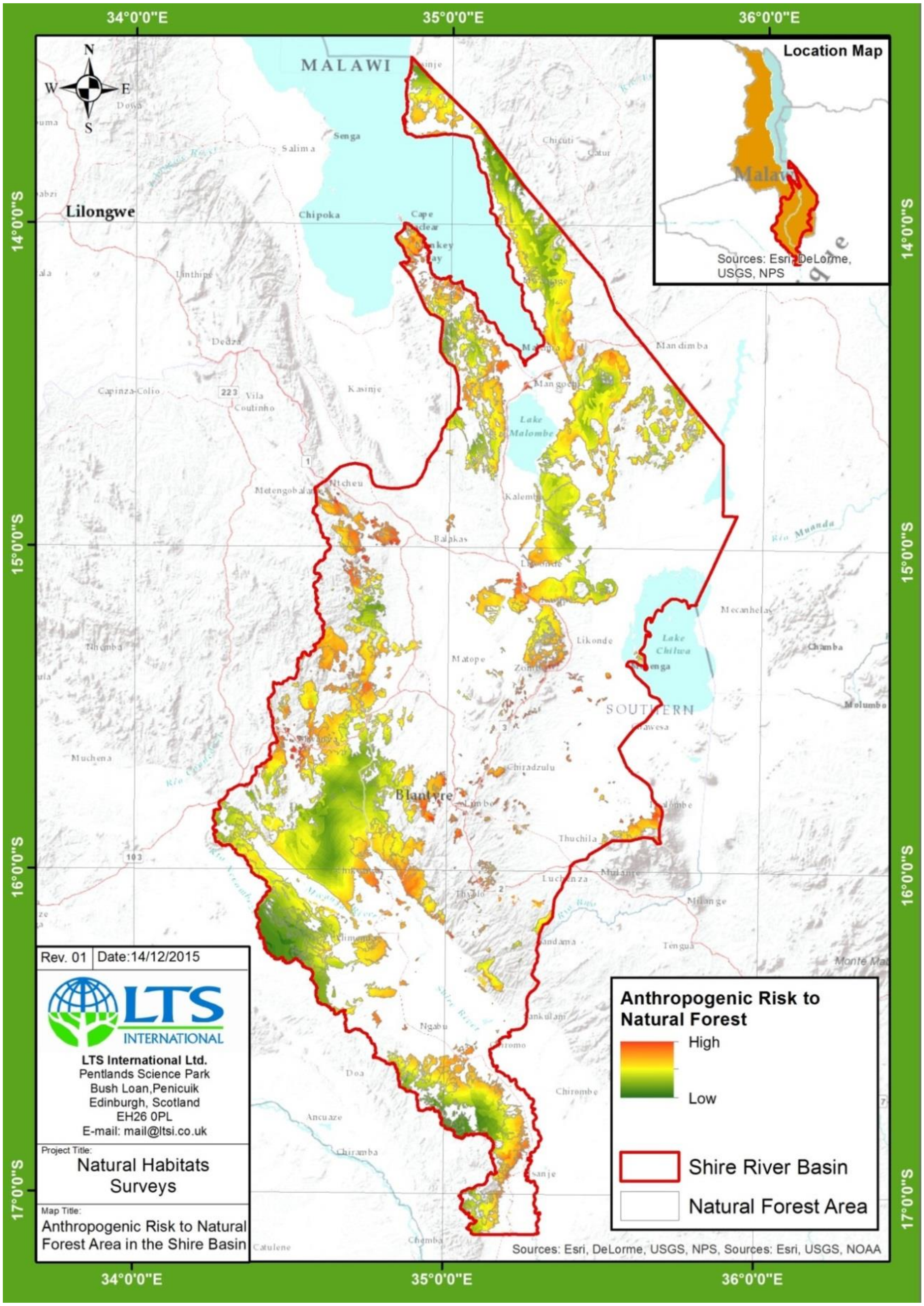


Fig. 3.5 Anthropogenic Threats to Forests in the Shire River Basin



3.2 Results from Analysis of Plant Samples

A second, and most important, category of results produced by the Natural Habitats Surveys component of the SRBMP during Year 1 is based on the analysis of the plant samples collected throughout the Basin. Sections below describe some of the most significant results.

3.2.1 Plant Species Diversity

A total of 1,134 species were identified among the approximately 4,200 specimens collected at the 52 sampling sites. Number of species per site ranged from low of 29 to high of 134 (Annex D). These species belonged to 569 genera and 147 families. Species of the family Fabaceae (legumes) are dominant, along with the Asteraceae, Rubiaceae, Poaceae, and Acanthaceae, which is typical for the flora of the Zambezian Regional Centre of Endemism.

Because a large majority of all species found at each sampling site were collected and identified, the RBS data give a reasonably complete sample of plant species diversity in the SRBMP project area.

Eighty-five specimens collected during the RBS field surveys have so far only been identified to the family or genus level. The most likely reason for this is that they are partial or incomplete specimens, which could be identified as known species only if flowers, fruits, or additional specimens were collected. However, there is a small possibility that these could represent new, undescribed species. We are currently working to check in improve the identifications of these specimens and will be reported in subsequent technical reports.

Information about species diversity is important for a number of reasons, but in the case of the SRBMP and its objectives, the main importance has to do with the relationship between species diversity, ecosystem function, and the ecosystem services that natural ecosystems provide to people. Recent ecological research points toward a positive relationship between species diversity and the stability or resilience of ecosystem functioning. In a 1998 paper titled "Ecological Resilience, Biodiversity, and Scale" the authors (Peterson *et al.*) wrote: "One of the central questions in ecology is how biological diversity [here they refer to species-level diversity] relates to ecological function. This question has become increasingly relevant as anthropogenic transformation of the earth has intensified. Maintaining the ecological services that support humanity, and other life, during this extensive and rapid ecological reorganization requires understanding how ecological interactions among species produce resilient ecosystems."

In their 2012 article "Biodiversity Loss and Its Impact on Humanity," Cardinale and colleagues (Cardinale et al., 2012) reviewed more than 1,700 published papers to summarize the current scientific evidence linking the diversity of species in ecosystems to the products and services they produce. More than 600 of these articles were based on experimental evidence from studies conducted in the past 25 years. The authors phrase their conclusions as "consensus statements" of the state-of-the-art of biodiversity-and-ecosystem-services science: "There is now unequivocal evidence that biodiversity [species] loss reduces the efficiency by which ecological communities capture biologically essential resources, produce biomass, decompose and recycle biologically essential nutrients." And, "There is mounting evidence that biodiversity increases the stability of ecosystem functions through time."

In another recent synthesis article in the prestigious journal ***Science***, titled "The Functions of Biological Diversity in an Age of Extinction," the authors (Naeem *et al*., 2012) state that: "Biodiversity and ecosystem functioning research is now maturing; it has advanced sufficiently to move beyond simply invoking the precautionary principle as it has done throughout its history. This research has helped to clarify why protecting biodiversity [species-level diversity] is a goal of fundamental importance and can support efforts to safeguard the intrinsic capacity of ecosystems for self-renewal, adaptive dynamics, and supporting humanity now and for generations to come."

3.2.2 Vegetation Classification

Ordination and classification summarize similarities and differences between samples in terms of all species and tree canopy species. In a statistical analysis called ordination, all species are treated as equal units, and the similarity between plant communities is calculated in terms of numbers (and abundances) of species in common, or not, between all pairs of samples. Two forms of ordination, Twinspan and detrended correspondence analysis (DECORANA) were used to analyse the Natural Habitats Surveys sample data. Both gave very similar results, and the DECORANA results are shown in figures below.

In ordination, the similarity between samples in terms of the species they contain is expressed as the distance between them. This can be plotted in two dimensions on a graph. Then, groups or clusters of samples that fall close to each other on the graph can be selected to enclose classes of samples that appear to represent distinct vegetation types. Most vegetation maps have to show polygons of discrete types, and for practical reasons there are usually a rather limited number of classes (e.g., 8-12).

Fig. 3.6 Detrended Correspondence Analysis (DECORANA) ordination results for Shire Basin RBS samples. Samples containing more similar plant communities are closer together on these axes. Tentative vegetation classes (labelled "VEGNUM" in the key) are shown as colours.

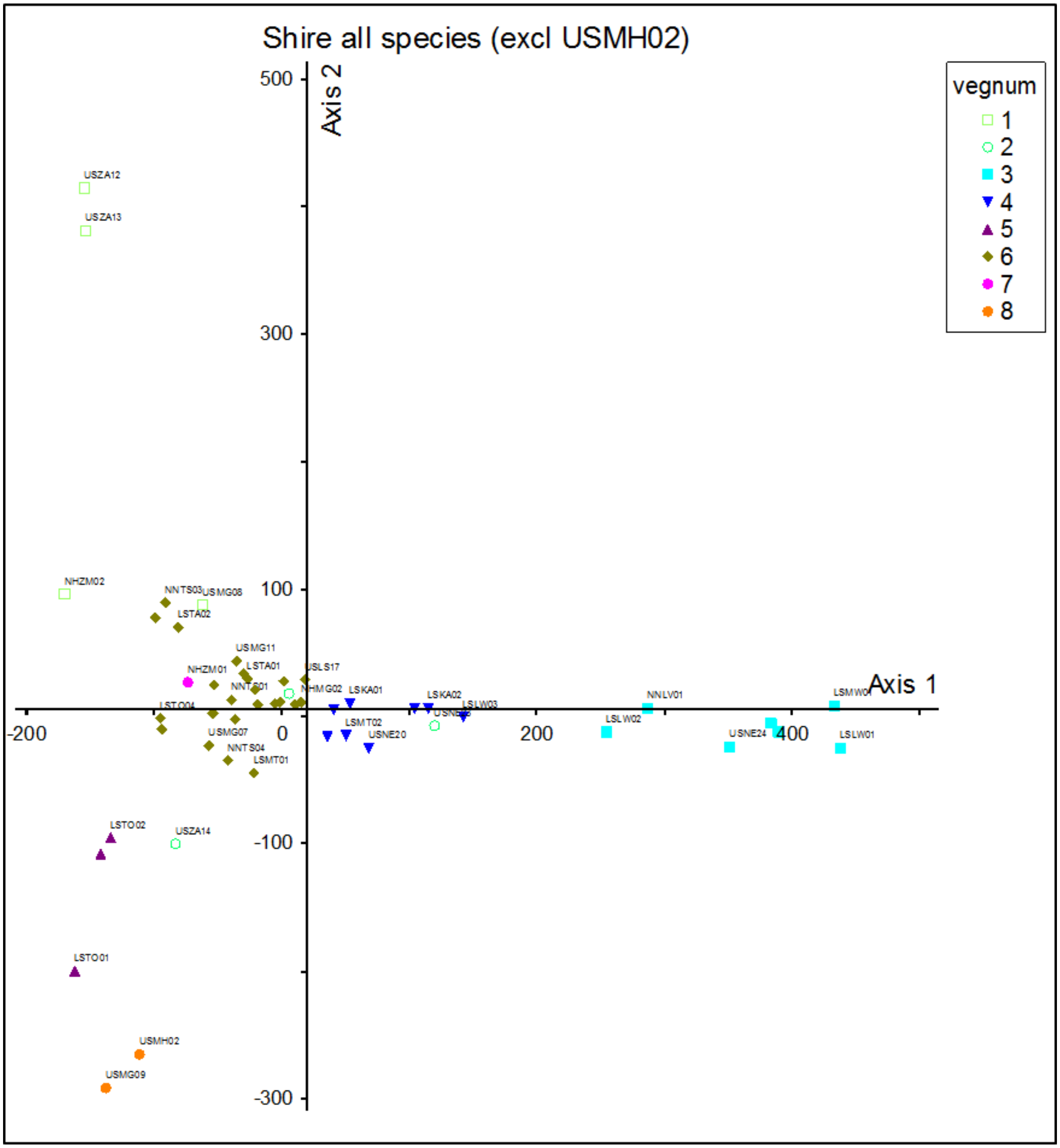
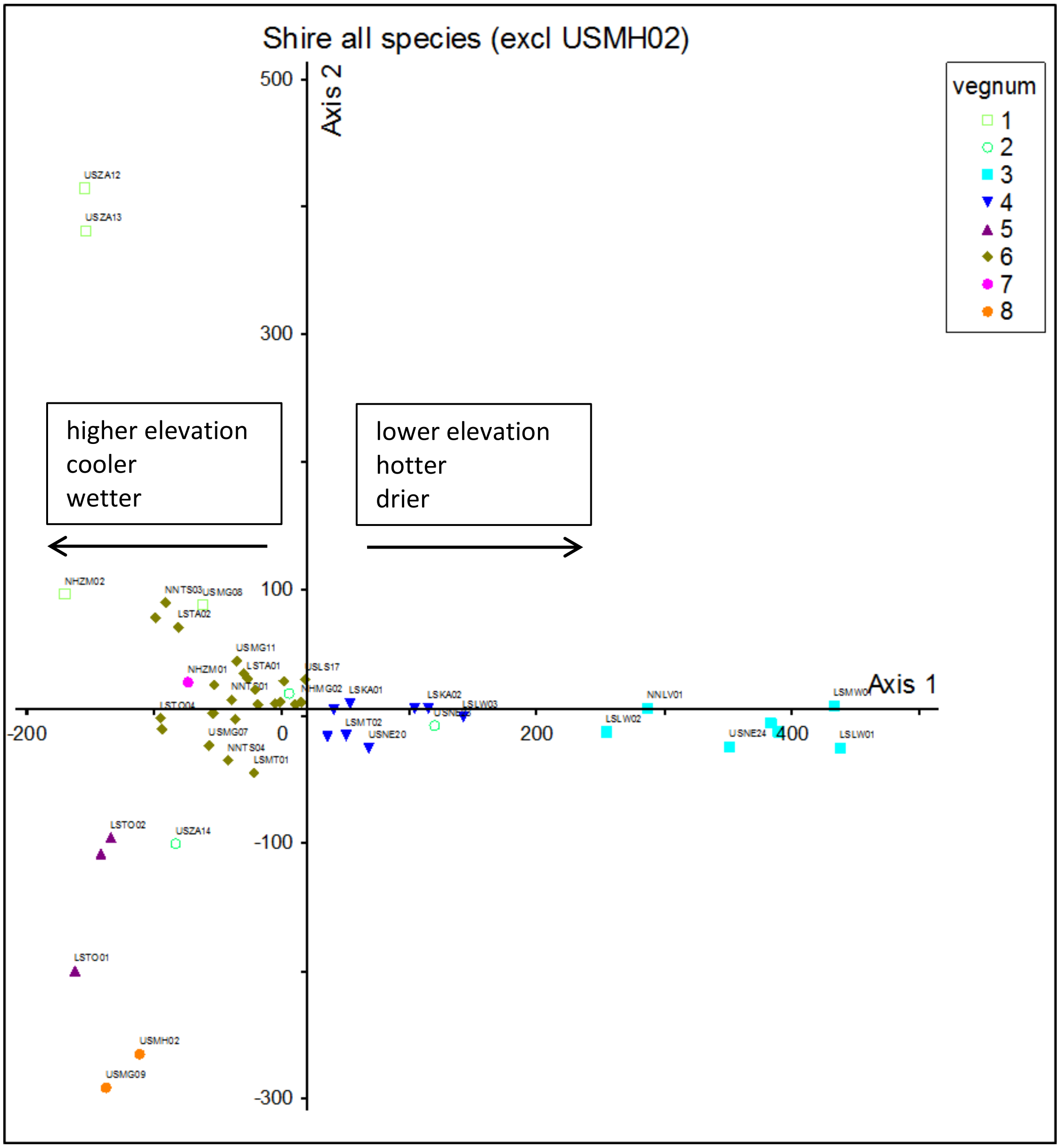


Table 3.4 Vegetation classification based on ordination of Shire Basin RBS ordination (see Fig. 3.5)

Vegetation Class	Symbol/Color (see Fig 3.5)	Vegetation Description	Elevation (m)
1		Montane grassland with few or no large trees	1179-1940
2		Degraded *Brachystegia* woodland with few or no large trees; would be Class 4 or 6 if large trees had not been removed	540-880
3		North Zambezian undifferentiated woodland including mopane, baobab, thickets	50-200
4		Mixed miombo woodland on sandy loam or stony ground, in most cases associated with watersources at lower elevation	50-120
5		Thyolo Tea Estates, riverine and alluvial evergreen forest	1000-1150
6		Miombo, *Brachystegia* woodland on hills and rocky outcrops, at 600-1400m.	600-1400
7		Disturbed/secondary montane forest on Zomba Mountain	1950
8		Afromontane evergreen forest at 1200-1700m on Mangochi Mtn. and Chikala ridge on loamy, humus-rich forest soils	1200-1700
9	---	Montane grassland with *Protea* in Mangochi Valley	908

Fig. 3.7 Interpretation of axes separating plant communities



Axis 1 correlates with elevation and precipitation, with higher-elevation, wetter plant communities to the left, lower and drier to the right.

Axis 1 is correlated with altitude, with lowland sites (and Classes 3 and 4) to the right. The differences between montane woodland (low Axis 2) and grassland (high Axis 2) are expressed up Axis 2. The low to mid-altitude miombo woodland samples are clustered around the origin.

Vegetation Class 1 is montane grassland or shrubland above 1100m, with few trees and subject to fires. The sample (USZA12) on Malosa Mountain, recorded as recently burnt, nevertheless has the highest level of globally-rare, restricted-range species in the whole survey (GHI=445), a very hot spot on a global basis. The successional status of this kind of Afromontane grassland, and the role of anthropogenic fire in maintaining it, is the subject of ecological debate. Although many such areas of montane grassland might become forest in the absence of fires, and fires are often set by people, the open grassland supports several near-endemic species, which must have evolved in similar habitats that must have therefore been present for tens of thousands of years.

The ecosystem service value of high mountain vegetation of any type, whether grassland or forest, is very high, because the vegetation retains soils and acts as a sponge to absorb precipitation and channel it to ground water. Vegetation and species, such as *Xerophyta splendens*, that can provide such services without being lost to fire makes them particularly valuable because of their contribution to ecological resilience.

Zomba-Malosa Forest Reserve, montane grassland (Vegetation Class 1), recently burned, in vicinity of RBS sample site USZA12. Photo: LTS/D. Mauambeta

Vegetation Class 2 is vegetation that would be classed as *Brachystegia* woodland (miombo woodland) in Class 4 or Class 6 if any larger trees were present, because they include many of the species of those classes, including the more rare species. Therefore, it can be assumed that in the absence of charcoal making and other tree harvesting, the original miombo woodland would regenerate.

Vegetation Class 3 could be called North Zambezian undifferentiated woodland, and included mopane and baobab woodland, and thickets and recently disturbed vegetation, particularly in Lengwe NP. This vegetation was found at lower elevations, often on sandy soils, presumably rather dry vegetation.

Vegetation Class 4 is mixed miombo woodland on sandy loam or stony ground, in most cases associated with water sources at lower elevations.

All the RBS samples from the Thyolo tea estates can be classified in *Vegetation Class 5*, variously described on the field forms as hilltop evergreen forest, low-slope riverine/evergreen forest, and alluvial evergreen forest. This flora is intermediate between montane evergreen forest (Class 8) and higher-elevation, wetter miombo (Class 6), but includes many exotic species, like chili pepper, mango, pine, and Eucalyptus. This is a flora heavily influenced by people, and with few globally-rare, restricted range species.

Vegetation Class 6 is *Brachystegia* woodland, miombo, on hills and rocky outcrops, at between 600-1400 m in elevation. Many of the samples were riparian woodland, or even called riparian forest. This vegetation class was the most common among the 52 sampled sites. It is often heavily exploited, such as for charcoal production, and larger trees are being lost at many sites.

Vegetation in Class 7 was a single, disturbed and second-growth montane forest on Zomba Mountain. The main priority of this patch would be its importance in helping the mountain top catch and retain water. It is a small remnant on the ridge top that could act as a source for restoring more degraded patches nearby. It is probably also important as a corridor for animal species trying to traverse the fragmented montane forest landscape.

Vegetation Class 8 is Afromontane evergreen forest at between 1200-1700 m in elevation, sampled on Mangochi Mountain and on the Chikala Ridge. They deserve maximum protection due to the watershed-protection services, and the fairly high levels of rare/restricted range species.

One sampled area was classed as *Vegetation Class 9*, a *Protea*-dominated grassland in a valley near Mangochi Mountain. This site had the second highest level of rare/restricted range plants among the 52 sites.

3.2.3 Vegetation Condition and Regeneration Potential

Disturbance of a natural habitat, such as direct human use of trees and other plant species, or fire, influences the composition and physical structure of the vegetation. Analysis of RBS field survey data can indicate how such disturbances are reflected in the plant community.

In the analysis of data from the 52 sampling sites, ordination showed that large tree cover can vary from low to high in any of the sampled communities, and therefore in itself is not a good indicator of overall plant community composition. However, the relative abundance of large tree cover can provide a measure of the level of human use or "disturbance."

Zomba-Malosa Forest Reserve, dry northern escarpment in Chingale SRBMP Priority Catchment, vicinity of RBS sample sites USZA14 and USZA15 (Vegetation Class 6). Photo: LTS/D. Mauambeta

Zomba-Malosa Forest Reserve, dry northern escarpment in Chingale SRBMP Priority Catchment, vicinity of RBS sample site USZA15 (Vegetation Class 6) with charcoal making. Photo: LTS/D. Mauambeta

The three sparse woodland sites that were placed into Vegetation Class 2 by the ordination analysis have a very similar species composition to miombo woodland in Class 4 or Class 6 (either higher or lower elevation miombo woodland) where the tree community is better-developed. Sites in Vegetation Class 2 include a site in Liwonde Forest Reserve (USMG10), Malosa FR (USZA14), and Neno East Escarpment (USNE23). This result indicates that tree cutting and removal, or possibly tree loss due to fire, can affect populations of larger trees, but that in itself it doesn't always influence the species composition of the whole community. That is, small individuals of the same species found as canopy trees in undisturbed communities may be present, but they are not big enough to reach the minimum diameter threshold to be counted in the RBS survey. This suggests, in turn, that if the factors that are removing large trees from the community (e.g., charcoal production) were controlled through management actions, tree cover could likely be restored through natural processes of woodland regeneration.

Zomba-Malosa Forest Reserve, dry northern escarpment in Chingale SRBMP Priority Catchment, vicinity of RBS sample site USZA14 (Vegetation Class 2); water from Katingere Stream used for irrigating gardens. Photo: LTS/D. Mauambeta

3.2.4 Presence of Globally-Rare, Restricted-Range Species

The presence of globally-rare, restricted-range species in an RBS survey sample can be determined by comparing it with a database of such species. Narrow or local endemics – the most restricted and rare – are those species that may be "endemic to a small part of a region (a mountain range or forest block, small island groups, or corners of a region with unusual rainfall patterns) where they might be locally common, or scattered within a slightly wider range… species known only from the type locality, or from there and a few areas within c. 100km," or "species known only from a few scattered mountain tops in a region would also qualify" (Hawthorne and Marshall, 2015). Data from all 52 RBS samples showed the following breakdown of global endemism.

Table 3.5 Number of species by global range category in Shire Basin RBS samples.

Global restricted range/rarity category	Number species identified in Shire Basin RBS
Most restricted/rare ("Black Star")*	36
Somewhat restricted/rare ("Gold Star")	53
Intermediate range/commonness ("Blue Star")	262
Common and widespread ("Green Star")	741
Total species	1092

*Note: "star" designations are from Hawthorne and Marshall, 2015

It is noteworthy that 36 species were collected that are in the most globally-rare, restricted range category, and another 53 species are quite somewhat regionally endemic (Table 3.5). Annex A discusses these globally rare species in greater depth, providing information on their range restrictions and lists all endemic and near-endemic species in sub-annex A2. Although all black star species are globally rare, of those found during the surveys, 7 appear to be Malawi-endemic and 10 are near-endemic (i.e. found in Malawi but also in nearby countries close to their common border, such as some sites Mozambique, for example).

Hawthorne and Marshall (2015) have developed a scoring system to quantify the level of globally restricted-range plants in a sample, which they call a "Genetic Heat Index," or "GHI," score. For comparative purposes, for example, the floras of non-tropical countries (e.g., United Kingdom, Canada, Argentina) typically have GHI scores of 50 or less, with many common and widespread species. Tropical countries, with high species-level biodiversity, may have GHI scores of 450-500 (e.g. Cameroon, Ecuador). A GHI index score can be calculated for each site sampled, and such an index provides an estimate of the uniqueness of a site in the context of global species diversity. When GHI scores were calculated for the 52 samples from our RBS surveys in the Shire Basin, the scores show a medium level of restricted-range species, with an overall average GHI score of 205, ranging from a low of 34 at a Lisungwi Valley disturbed woodland site to a high of 445 at Malosa Mountain in montane grassland (which Hawthorne described as "a very hot spot on a global basis.")

Zomba-Malosa Forest Reserve, montane grassland (Vegetation Class 1), recently burned; team working at RBS sample site USZA12. Photo: LTS/D. Mauambeta

Zomba-Malosa Forest Reserve, vicinity of RBS sample site USZA12. Photo: LTS/D. Mauambeta

High-elevation sites tend to have more globally-rare, restricted-range species than lower elevation sites. Table 3.6 shows the three sites with highest levels of restricted range species found in all 52 sample sites, all in montane grassland or forest ecosystems.

Table 3.6 Summary information for three montane sites with high levels of globally-rare, restricted range species.

Site	Description	Elevation (m)	GHI score	# most restricted/rare species ("Black Star")	# somewhat restricted/rare species ("Gold Star")
Malosa Mountain (USZA12)	montane grassland - recently burned	1891	445	6	6
Mangochi FR (USMH05)	montane grassland with *Protea*	908	377	3	0
Mangochi Mountain Ridge (USMH02)	montane evergreen forest	1663	281	3	6

Even some higher-elevation miombo woodland sites harbor species of significant global uniqueness. The site with the fourth-highest level of globally-rare, restricted range species was a higher elevation miombo woodland site in Zomba-Malosa Forest Reserve, a dry northern escarpment area in the SRBMP Chingale Priority Catchment, at an elevation of 968 m (USZA15). This site had a GHI score of 258 (3 most restricted/rare and 3 somewhat restricted/rare species). This site was just uphill from, but very near the Zomba-Malosa FR site with Vegetation Class 2 (USZA14) – a site of high natural regeneration potential for miombo woodland regeneration potential site along the Katingere Stream. With a nearby miombo woodland site containing a significant level of globally rare/restricted range species, it seems likely that, if miombo was allowed to regenerate at the Katingere Stream site, some of those globally rare/restricted range species would be present also.

A Neno East Escarpment site (USNE21) had a GHI score of 222 (3 most restricted/rare and 1 somewhat restricted/rare species). A site in the Liwonde Forest Reserve (USMG10) that was classed as Vegetation Class 2 – and therefore a site of high natural regeneration potential for miombo woodland – nevertheless had a relatively high GHI score of 216 (2 most restricted/rare and 5 somewhat restricted/rare species). It is very interesting finding that nearby two of the three areas classified as Vegetation Class 2 “regeneration potential” sites are higher-elevation miombo woodland sites.

4. Institutional Capacity Building

As highlighted in our Inception Report, an important aspect of this work is to foster capacity building, knowledge exchange and partnership development with key institutions in Malawi that are concerned with biodiversity management. Over the course of Year 1 we have worked closely with our host institutions, the National Herbarium and Botanic Gardens, and the Forestry Research Institute of Malawi, to improve and strengthen their capacity.

A baseline institutional capacity assessment of these partner institutions was described in our Inception Report. The assessment considered:

- Human and physical resources;
- Biodiversity qualifications and plant identification skill and knowledge
- Capacity for biodiversity survey planning
- Capacity for biodiversity survey execution
- Capacity for data analysis

The site selection workshop and rapid botanic surveys (RBS) training that took place in Zomba in June developed some of this capacity. Capacity was increased through classroom and field-level training in the internationally-recognized RBS methodology, which is new to Malawi, and which allows very rapid yet detailed surveys of natural habitats and vegetation. Training was also conducted in the use of the Botanical Records and Herbarium Management System (BRAHMS), through a training course held in December 2014. Fifteen staff members from NHBG and FRIM were trained during the June workshop. Twelve of those staff members participated in the field surveys during a period of eight weeks in June-August 2015, gaining valuable "hands-on" experience.

At the November presentation of Year 1 results in Zomba we used a short survey to better understand the degree to which the RBS training and field experience had affected the participants. One question was: "Do you expect to use the skills and knowledge you learned in the RBS process in your work in the future?" Responses from the nine staff members who had participated in the fieldwork in some way were:

1. no N=0
2. unlikely N=0
3. maybe N=1

4. probably N=1
5. certainly N=7

Their comments gave further weight to this strongly positive finding. Comments included:

- "very, very important process"
- "we collected a lot of different plant species right away in their habitats"
- "certainly, because the method uses less time and resources while providing equally the best results"
- "RBS methodology is handy and exciting. Very useful for research and teaching."

However, one message that came through very clearly in the discussion following the written evaluation survey was the view that the training and capacity-building process was incomplete, because after Malawian teams collected the plant data, and the information was sent to Oxford University for statistical analysis by an international expert. Many participants said they felt that training should also be offered in the data analysis and interpretation, so they could carry out the analysis of the botanical information collected using the RBS methodology themselves.

5. Conclusions and Recommendations

The Year 1 results of the Natural Habitats Surveys activity, including our geospatial analysis, modelling, and mapping results and the results of the field-based surveys of plant biodiversity, provide a rationale for prioritizing our Year 2 work. The results suggest our strategic focus should be on conducting further studies at five priority protected areas: Mangochi, Liwonde, Zomba-Malosa, Neno East, and Tsamba Forest Reserves. Discussions in November 2015, at our presentation of Year 1 Results in Zomba, led to a feeling of consensus that these five sites would be the highest priority for further studies in Year 2 for the reasons indicated here:

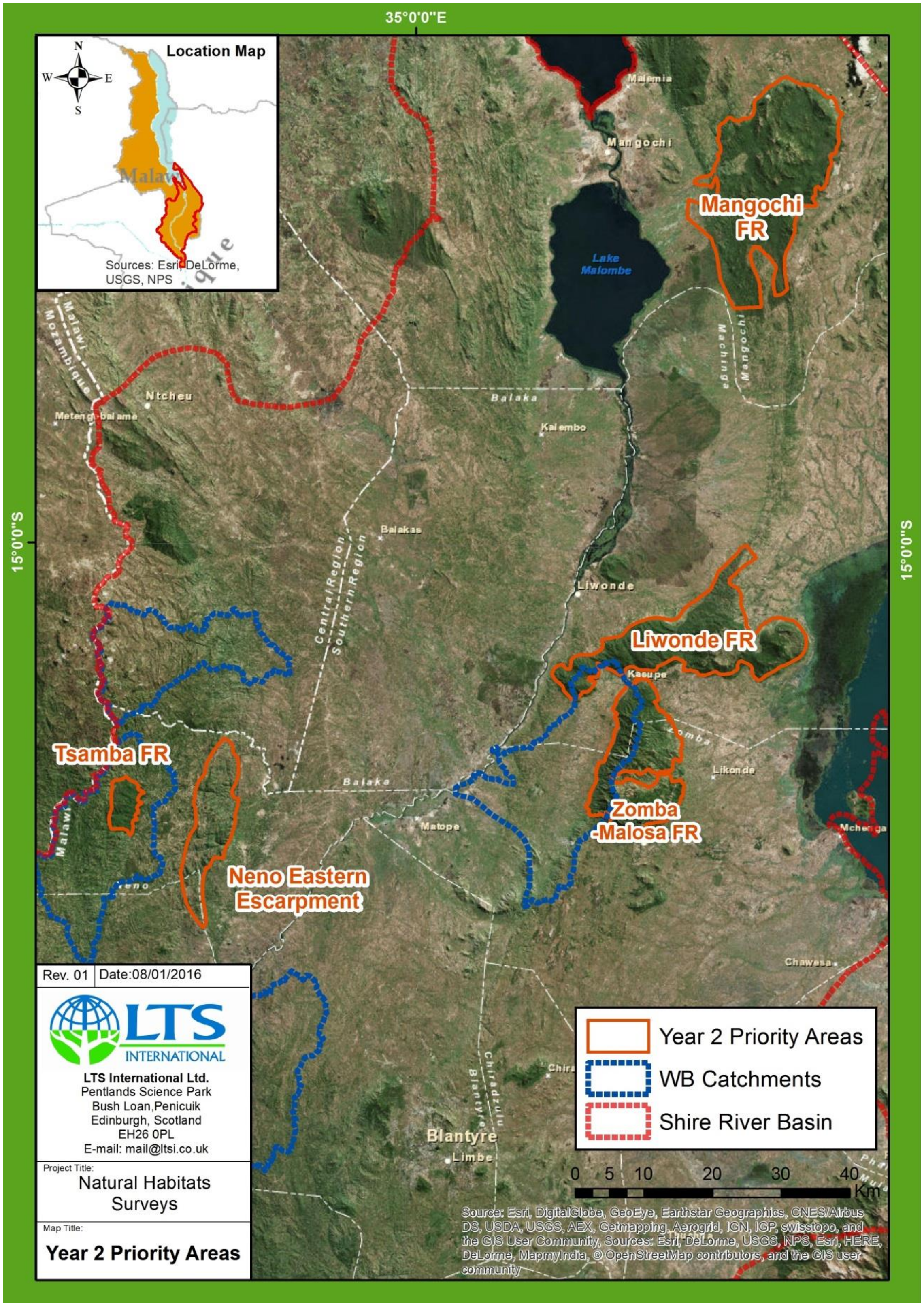
- Mangochi FR – this area had two of the three sites with the highest levels of globally-rare, restricted range species found in our survey of the Shire Basin, in montane evergreen forest and montane grassland with *Protea*.
- Liwonde FR – this area had one of the three sites with high potential for the regeneration of miombo woodland, and a nearby site with a high level of globally-rare, restricted range species.
- Zomba-Malosa FR – this area had a site in high montane grassland with the highest level of globally-rare, restricted range species of all 52 sites sampled, a level comparable with other "hot" sites globally. It also had one of the three sites with high potential for the regeneration of miombo woodland, and a nearby site with a high level of globally-rare, restricted range species. Those sites were also in the Chingale Catchment, one of the four Priority Catchments of the SRBMP.
- Neno East Escarpment (proposed FR) – had one of the three sites with high potential for the regeneration of miombo woodland, and a nearby site with a high level of globally-rare, restricted range species.
- Tsamba FR – Sites in this area were generally well-conserved, presenting an example of intact miombo woodland, a "witness stand" against which the condition and regeneration of miombo woodland at other sites can be compared. The Tsamba FR is in the Upper Wamkulumadzi Catchment, one of the four Priority Catchments of the SRBMP

The types of studies we are proposing for Year 2 are summarized below. The matrix shown in Table 5.1 constitutes a "menu" of options, to be factored against financial and human resources available in the Year 2 budget of the Natural Habitats Surveys component. Given budgetary limitations, it is clear that not all types of activities can be carried out at all sites.

Table 5.1 Year 2 Priorities and Options (see Fig 3.9 also)

Area	Priority Theme for Year 2 Activities				
	Regeneration Potential	Globally-rare Restricted range species	Intactness ("Witness Stand" or Ecological "Control" Habitat)	Economic Value of Hydrological Services	Economic and Livelihood Value of Ecosystem Products
Mangochi FR		X (montane evergreen forest and montane grassland)		X	X
Liwonde FR	X	X (in miombo)		X	X
Malosa FR	X	X (montane grassland and in miombo)		X	X
Neno East Escarpment	X	X (in miombo)		X	X
Tsamba FR			X	X	X

Fig. 5.1 – Year 2 Priority areas



Detailed Studies of Regeneration Potential

Further analysis of regeneration potential should be conducted at selected sites, with the goal of strengthening information about natural forest regeneration that can eventually inform management recommendations in the Shire River Basin, and develop knowledge product(s) to that end. Further studies to characterize natural regeneration potential in areas in Vegetation Class 2 in Liwonde FR, Malosa FR, and Neno East proposed FR should be conducted. These will underpin a knowledge product aimed at providing guidance for natural regeneration at these and other sites. Fieldwork in less disturbed areas (e.g. Tsamba FR) may be needed to understand the temporal dynamics of miombo regeneration. These studies would be spearheaded by a team from FRIM.

5.1 Detailed Studies of Globally-Rare, Restricted-Range Plants

Further study of globally-rare/restricted range plants to characterize populations, inform management decisions, and develop knowledge product(s). Further studies to characterize the populations of the most globally-rare/restricted range species at sites with the highest GRI scores (Malosa montane grassland, Mangochi Mountain montane evergreen forest, Mangochi valley grassland with *Protea,* and Malosa FR Chingale dry northern escarpment) should be conducted. Searches would be conducted at the same sample plots as in Year 1 for globally-rare, restricted range species that contribute the most to the high GHI scores at those sites. The status of their populations would be characterized. These studies would be spearheaded by a team from NHBG.

5.2 Zoological Studies at Selected Sites

Sites for focused zoological studies would be selected according to prioritization criteria discussed below, and based on the results of desk-based analysis and field work carried out throughout Year 1. Limitations of Year 2 resources will probably limit these studies to a few of the highest priority site-by-taxon studies. For certain groups (e.g., birds, large mammals), local Malawian experts could conduct the surveys. For other groups (e.g., butterflies), it is likely that an international specialist would have to be contracted to lead the survey, and the expectation is that they would work with a Malawian counterpart to train them and build national capacity. The goal would be to identify species that were indicator species of more general ecosystem health and function, and/or "flagship" species that could be used to motivate conservation actions in the area where they are found, and/or themselves "keystone" species, influential in structuring the natural habitat in which they were found (e.g., elephants).

5.2.1 Zoological Information and Gaps

We conducted a desk review of the current state of zoological information for the five areas that had either high regeneration potential sites (Vegetation Class 2) or high levels of globally-rare, restricted range species according to the analysis of RBS survey data, which were some of the criteria used to recommend Year 2 priority sites. This review identified the extent and date of available zoological information, focusing mainly on the following animal taxa: birds, large mammals, butterflies, reptiles and amphibians, small mammals including bats, and other insects (see Annex B). Information was characterized as "strong," "some available," "weak/old," or "none." The general conclusion, visually summarized in Table 5.2 below, is that zoological information is in general very weak – further information on what information does exist for these areas is given in Annex B. Figure 5.1 places these sites within the context of the overall basin.

Table 5.2 Level of zoological information at priority sites

Area/Site	**Animal Taxa**							
	Birds	Large mammals	Small mammals incl. bats	Reptiles and amphibians	Butterflies	Other insects	IUCN Red List Animals	Other?
Mangochi								
Liwonde								
Malosa								
Neno East								
Tsamba								

None

Weak

Some

This information can be used to prioritize potential Year 2 zoological studies by site.

Two principles should be kept in mind in doing so:

1) Because plants are the base of the food web, because of co-evolved relationships such as plant-pollinator and larval host plant relationships, zoological biodiversity can be expected to correlate with plant biodiversity.

2) Because similar evolutionary forces of allopatric speciation may be responsible for plant and animal species diversity and endemism, sites of high plant diversity and/or endemism may be the best place to look for the same in zoological taxa.

Protea with beetles, Zomba-Malosa Forest Reserve, montane grassland sample site USZA12. Photo: LTS/D. Mauambeta

Criteria for prioritizing an animal taxon and/or site would include whether there was an opportunity to:

- close a knowledge gap;
- detect a trend in the presence or abundance of an animal taxon or species through repeating a past study in an area; and
- because an animal taxon/species seems likely to be an "indicator," "keystone," or "flagship" species.

Because zoological information is generally weak, the knowledge base regarding that taxon would be strengthened for almost any taxon could be chosen for zoological field study. This criterion does not, therefore, offer much promise for prioritization. The second criterion, detecting a trend by repeating a past study, would prioritize repeating bird surveys at Mangochi, Liwonde, and Zomba-Malosa Forest Reserves, and perhaps an insect study at Malosa. Birds and butterflies, because of the wider knowledge base that exists about them and the relative ease of observing them, are probably the most promising candidates for "indicator" species. Larger mammals that are hunted by local communities, such as small antelopes, could perhaps serve as indicator species in some areas. Elephants would be the main "keystone" species of concern.

5.3 Modelling Economic Value of Hydrological Ecosystem Services

Modelling will be used to estimate the economic values for hydrological services at the five Year 2 priority areas. These values include the values of water captured by those areas for domestic supply, hydropower, and irrigation; the value of flow stabilization from forest cover in preventing flooding; the value of soil retention and sediment reduction to downstream users; and the value of water for environmental flows in downstream areas of importance to biodiversity, including Elephant Marsh.

5.4 Economic Valuation Study of Key Ecosystem Products

Estimated economic and livelihood values for ecosystem products from one or more of the Year 2 priority sites to local communities will be determined by desk and field study. Products of potential value include firewood, charcoal, poles, thatching grass, bamboo, reeds, mushrooms, wild fruits, medicinal plants, bushmeat, and edible insects.

5.5 Training in BRAHMS Data Analysis

One message that came through very clearly in the discussion following our presentation (and in the written evaluation survey we gave to participants at the end) was the view that the RBS training and capacity-building process was incomplete, because after Malawians collected the plant data, it was analysed statistically by an international expert at Oxford University. In Year 2, training in basic statistical analysis (e.g., ordination using DECORANA or Twinspan) should also be offered, so that Malawian staff of NHBG and FRIM could carry out future data extraction, manipulation, analysis, and interpretation themselves. The data collected as part of this project will be reincorporated into BRAHMS at NHBG at the earliest possible opportunity.

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