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BIODIVERSITY BASELINE SURVEY:
FIELD MANUAL

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Ministry of Environment and Natural Resources, Sri Lanka

IN ASSOCIATION WITH
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GREENTECH CONSULTANTS

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CONTENTS

1. BACKGROUND AND CONTEXT
   What is biological diversity? 1
   Why identify and monitor biological diversity? 1
   Convention on Biological Diversity 2
   What is known about Sri Lanka’s biological diversity? 3
   Biodiversity Baseline Survey 5
   Purpose and content of this field manual 6

2. SAMPLING BIOLOGICAL DIVERSITY
   2.1 Introduction 7
   2.2 Sampling considerations 7
   2.3 Sampling adequacy and inventory evaluation 8
   2.4 Alternatives to species inventories 9
   2.5 Conclusions 9

3. FIELD SURVEY METHODS
   3.1 Biodiversity Baseline Survey protocol 10
   3.2 Habitat condition and conservation status of associated species 10
   3.3 Stratified and gradsect sampling of terrestrial habitats 11
   3.4 Quantitative integrated sampling design for terrestrial habitats 12
   3.5 Quantitative sampling design for aquatic habitats 14
   3.6 Sampling methods 15
   3.7 Resource requirements 20

4. COLLECTING, PRESERVING AND IDENTIFYING SPECIMENS
   4.1 Legal and ethical considerations 21
   4.2 Plants 21
   4.3 Animals 25
   4.4 Identification 27

5. MANAGING THE FIELD DATA
   5.1 Methods and process 28
   5.2 Technology considerations 29
   5.3 Application overview 30
   5.4 Future opportunities 31

6. ANALYSING THE RESULTS
   6.1 Data screening 32
   6.2 Data appraisal - assessing effectiveness of sampling 32
   6.3 Species diversity 33
   6.4 Interpreting diversity 35

7. MORE RAPID SURVEYS FOR MONITORING BIODIVERSITY
   7.1 Learning from experience 36
   7.2 Objectives and criteria 39
   7.3 More rapid field survey protocol 39
   7.4 Working in partnership 40

REFERENCES 42

Annex 1 Composition of Biodiversity Baseline Survey team 47
Annex 2 List of essential field equipment 48
Annex 3 Specimen labels for plants and animals 49
1. BACKGROUND AND CONTEXT

What is biological diversity?

Biological diversity is the variety of life on Earth (Box 1), the product of millions of years of evolution and thousands of years of cultivation of plants and domestication of animals. It is often referred to in abbreviated form as biodiversity. There are many levels of diversity, from DNA and genes to species, populations, communities and ecosystems. Biological diversity is often considered in terms of the diversity of genes, species and ecosystems – three fundamental and hierarchically-related levels of biological organisation (WCMC, 1992).

Box 1 Biological diversity, as defined in the Convention on Biological Diversity

“Biological diversity” means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems. [Article 2]

Genetic diversity refers to the variety of genes within living organisms, including plants and animals. It is measured by the variation in genes, the chemical units of hereditary information that may be passed from one generation to the next. Genetic diversity is linked to the survival of offspring. When small populations are isolated from other populations of their species, they may be forced to inbreed, possibly leading to a loss of genetic diversity and to the extinction of the population.

Species diversity refers to the variety of living organisms, including micro-organisms, fungi, plants and animals. It is measured by the total number of species within a given area of study. Species diversity is linked to the survival of ecosystems. When a species disappears, it can affect a whole ecosystem, as can the appearance of an invasive or exotic species. Some species depend on just a single host species to survive.

Ecosystem diversity refers to the variety of ecological complexes or habitats within which species occur. Their health is crucial for the well-being and survival of the species which they support, as well as for human welfare. Ecosystem diversity is difficult to quantify. While genes and species define themselves through replication, and communities may be classified relatively unambiguously, ecosystems tend not to exist as discrete units but represent parts of a highly variable natural continuum. Moreover, they include abiotic components, being partly determined by soil parent material and climate. Ecosystems are best appreciated in terms of the functions they fulfill and services they deliver (Millennium Ecosystem Assessment Board, 2005). For example, rainforests filter for the Earth's air, absorbing carbon dioxide and releasing oxygen. Oceans also absorb carbon dioxide, a greenhouse gas that causes global warming. Wetlands and estuaries filter the Earth's freshwaters and provide nurseries for marine populations.

Why identify and monitor biological diversity?

Understanding biological diversity in terms of the processes by which ecosystems function and their components, be it at community, species, population or genetic levels, is critical to informing its sustainable use and safeguarding it for the benefit of future generations.

Biological diversity is dynamic, continually evolving and changing in response to biotic and abiotic fluctuations and other environmental pressures. Thus, it is necessary to record or benchmark the status quo and subsequently monitor that status quo in order to record, assess and understand changes to biological diversity for purposes of its future management.
Protected areas provide outdoor laboratories for the study of biological diversity. They are particularly important locations for its study because they are usually designated on account of their relatively high levels of biological diversity and they are protected for purposes of its conservation. Monitoring trends and changes in the distribution and abundance of individual populations and assemblages of species of plants and animals provides a means of assessing the effectiveness with which such protected areas are managed, while also identifying impacts (positive and negative) that are driven by external forces, such as aerial or water-borne pollution from distant sources and climate change.

Clearly, identifying and monitoring biological diversity is a huge and potentially infinite task given the many levels of diversity and their extensiveness, as defined in Section 1.1. For most practical purposes of conserving biological diversity in situ (i.e. in the wild, rather than ex situ in ‘captive’ collections of plants and animals), it is sufficient to focus on monitoring species and ecosystems. Only in a few cases where species are limited to one or two very small populations may it be necessary to monitor diversity at the genetic level to mitigate against potential inbreeding and extinction.

Much, but by no means all, of Sri Lanka’s biological diversity is represented within its network of protected areas, administered by either the Department of Wildlife Conservation or the Forest Department. Such protected areas, in theory though not always in reality, have been selected for their wealth of biological diversity and are safeguarded under various national legislation for long-term conservation purposes. Knowing what and how biological diversity is distributed within a protected area is essential for informing its future management, as well as providing context to the planning and management of the country’s entire system of protected areas. As relatively little is known about biological diversity within many of Sri Lanka’s protected areas, let alone outside protected areas, a priority is to identify and monitor the components of biological diversity within such protected areas, particularly since so much of the species diversity is endemic to this island country as discussed further in Section 1.4.

This task is urgent because biological diversity is being lost rapidly. Deforestation and degradation of forests, for example, has reduced closed canopy forest from 84% in 1888 to 24% in 1992 (Legg and Jewell, 1995), the causal factors being encroachment and alienation of forest land for settlement and agriculture (Forestry Planning Unit, 1995). Loss of habitat is accompanied by a reduction in the distribution and abundance of species and, in the case of endemics, may even result in their global extinction. According to the 14 volumes of A Revised Handbook to the Flora of Ceylon (Dassanayake et al., 1980-2000), for example, 133 (4.4%) of Sri Lanka’s 3,044 indigenous species have not accessioned by the National Herbarium, Peradeniya since the beginning of the 20th century. Of these, 63 are endemic, which amounts to 6.9% of the country’s 919 endemic species. While not necessarily extinct, there is a serious lack of knowledge about the conservation status of a significant component of the flora, underlining the importance of routinely monitoring such biological diversity.

**Convention on Biological Diversity**

Sri Lanka, as a signatory to the Convention on Biological Diversity, is obliged to identify and monitor the components of biological diversity important for its conservation and sustainable use. These provisions are contained in Article 7, reproduced in Box 2, and apply to the components of biological diversity both within (in-situ) and outside of (ex-situ) their natural habitats.

This obligation requires extensive field surveys to inventory species and the ecosystems of which they are a part, providing a benchmark, or record in time and space, against which future changes can be measured. Such surveys and repeat surveys provide the means of monitoring changes in biological diversity, assessing its conservation status and informing its management.

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1 Sri Lanka ratified the Convention on Biological Diversity in 1994.
What is known about Sri Lanka’s biological diversity?

Sri Lanka has a long geological history linked to southern Africa, Asia, Australia and South America when it was part of the ancient Gondwanaland some 160 million years ago. The Deccan plate, a fragment of this land mass comprising India and Sri Lanka, collided with the Asian plate around 55 million years later. Subsequently, 20 million years later in the late Miocene, the land between Sri Lanka and India became submerged, since when it has been above and below sea level on at least four occasions during the Pleistocene glaciations. The island was last connected to the Indian subcontinent some 10,000 years ago.

The island’s geological history, tropical location, diverse topography, including a wide range in altitude, and its varied climate, governed by seasonal monsoons (winds), are among the key factors that responsible for its extremely high levels of biological diversity and endemism. The long history of human civilisation, dating back to the 5th century BC, has further influenced the conservation status of this biological diversity in terms of its distribution and abundance.

Internationally, Sri Lanka, together with the Western Ghats in southern India, is a global hotspot for biological diversity (Myers et al., 2000), of which 34 are currently recognised (Mittermeier et al., 2005). These 34 hotspots are defined regions where 75% of the planet’s most threatened mammals, birds and amphibians survive within habitat covering just 2.3% of the Earth’s surface. To qualify as a hotspot, a region must meet two criteria: it must contain at least 1,500 species of vascular plants (> 0.5 percent of the world’s total) as endemics; and it must have lost at least 70% of its original habitat due to the impact of human activities. With respect to comprehensive global analyses of specific taxonomic groups, Sri Lanka is also recognised as:

- one of 234 centres of plant diversity in the world (Davis et al., 1995); and
- one of 221 endemic bird areas, as defined by Birdlife International (Stattersfield et al., 1998).
The wealth of species recorded for some of the better known and more conspicuous taxonomic groups of plants and animals is summarised in Table 1. Levels of endemism are extremely high for many groups. An extreme example is freshwater crabs; all 51 species are endemic and 26 species are known from only one locality (Bahir and Pethiyagoda, 2006). Much of this diversity is found in the montane, submontane and lowland rain forests of the wet zone and moist monsoon forests of the intermediate zone. It is also here that levels of endemism are highest, especially among flowering plants (Dassanayake et al., 1980-2000) and some of the less mobile faunal groups, such as tree-frogs, agamid lizards and skinks (Bambaradeniya, 2006).

**Table 1** Recorded diversity of Sri Lanka’s better known flora (Dassanayake et al., 1980-2000, Senaratna, 2001; MENR, 2002) and fauna (Bambaradeniya, 2006)

<table>
<thead>
<tr>
<th>Taxon</th>
<th>No. species</th>
<th>No. endemics</th>
<th>% endemics</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INDIGENOUS FLORA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Algae</td>
<td>896</td>
<td>unavailable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fungi</td>
<td>1,920</td>
<td>unavailable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lichens</td>
<td>110</td>
<td>39</td>
<td>28.2</td>
<td></td>
</tr>
<tr>
<td>Mosses</td>
<td>575</td>
<td>unavailable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liverworts</td>
<td>190</td>
<td>unavailable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ferns and allies</td>
<td>314</td>
<td>57</td>
<td>18.2</td>
<td></td>
</tr>
<tr>
<td>Gymnosperms</td>
<td>1</td>
<td>0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Angiosperms</td>
<td>3,044</td>
<td>919</td>
<td>30.2</td>
<td>Excludes 1,083 exotic species.</td>
</tr>
<tr>
<td><strong>INDIGENOUS INVERTEBRATE FAUNA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bees</td>
<td>148</td>
<td>21</td>
<td>14.2</td>
<td></td>
</tr>
<tr>
<td>Dragon/damselflies</td>
<td>120</td>
<td>57</td>
<td>47.5</td>
<td>Includes 4 new endemic species to be described.</td>
</tr>
<tr>
<td>Aphids</td>
<td>84</td>
<td>2</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td>Ants</td>
<td>181</td>
<td>1</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>Butterflies</td>
<td>243</td>
<td>20</td>
<td>8.2</td>
<td></td>
</tr>
<tr>
<td>Ticks</td>
<td>27</td>
<td>1</td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td>Spiders</td>
<td>501</td>
<td>unavailable</td>
<td></td>
<td>Total number of species likely to exceed 8,000.</td>
</tr>
<tr>
<td>Freshwater crabs</td>
<td>51</td>
<td>51</td>
<td>100.0</td>
<td>Of the 7 genera, 5 are endemic to Sri Lanka.</td>
</tr>
<tr>
<td>Land snails</td>
<td>246</td>
<td>204</td>
<td>82.9</td>
<td>Excludes 18 exotic, mostly agricultural species.</td>
</tr>
<tr>
<td><strong>VERTEBRATE FAUNA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freshwater fish</td>
<td>82</td>
<td>44</td>
<td>53.7</td>
<td>Excludes 22 species introduced since 1982.</td>
</tr>
<tr>
<td>Amphibians</td>
<td>102</td>
<td>88</td>
<td>86.3</td>
<td>Many more amphibian species await description.</td>
</tr>
<tr>
<td>Reptiles</td>
<td>184</td>
<td>105</td>
<td>57.1</td>
<td>Includes 5 marine turtle and 13 marine snake species.</td>
</tr>
<tr>
<td>Birds</td>
<td>482</td>
<td>25</td>
<td>5.2</td>
<td>Includes 220 breeding residents.</td>
</tr>
<tr>
<td>Mammals</td>
<td>91</td>
<td>16</td>
<td>17.6</td>
<td>Excludes 16 introduced and 27 marine mammal spp.</td>
</tr>
</tbody>
</table>

While much of Sri Lanka’s flora and fauna had been collected and described prior to the 20th century, many new species continue to be discovered and await scientific description, particularly among some of the invertebrate and smaller vertebrate groups. Spiders, for example, are poorly researched: 501 species are known but the actual number might exceed 4,000 species (Benjamin and Bambaradeniya, 2006). Among vertebrates, much recent collection and taxonomic review of amphibians has resulted in a near doubling of this fauna from 53 to 102 species, based on published descriptions. More new species await description: the total size of this group is currently estimated at about 140 species (Pethiyagoda, 2006).

Quantitative information about the distribution and conservation status of Sri Lanka’s biological diversity, even for the better known groups, is limited. Hence, the added importance of benchmarking and subsequently monitoring what occurs within the national system of protected areas. The most comprehensive nationwide survey to date is the National Conservation Review of forest biodiversity undertaken by the Forest Department in 1991-1996. Woody plants and selected animal groups within
all natural forests of 200 ha or more, except those occurring in the politically inaccessible northern and eastern parts of the country, were surveyed (Green and Gunawardena, 1997). A total of 1,153 woody plant, 64 butterfly, 71 mollusc, 32 amphibian, 65 reptile, 139 bird and 37 mammal species was recorded, representing a significant proportion of the diversity of each of these groups as summarised in Table 1. Other more recent biodiversity surveys have been carried out in greater detail for specific taxonomic groups, such as plants at Ritigala (Jayasuriya, A.H.M. 1984), Peak Wilderness (Singhakumara, 1995a) and Kanneliya-Dediyagala-Nakiyadeniya (Singhakumara, 1995b), amphibians and reptiles in the Knuckles (de Silva, 2005) and an island-wide survey of land snails (Naggs et al., 2005), but none covers the range of plant and animal groups, using quantitative methods, to the extent of the National Conservation Review or the present Biodiversity Baseline Survey.

**Biodiversity Baseline Survey**

The Biodiversity Baseline Survey is a discrete Contract within the Protected Area Management and Wildlife Conservation Project, funded by the Asian Development Bank, World Bank Global Environment Facility and the Government of the Netherlands. It has been undertaken by ARD Inc., in association with Infotechs Ideas (Pvt) Ltd and Greentech Consultants (Pvt) Ltd, for the Ministry of Environment & Natural Resources in accordance with the *Contract for Consulting Services of Biodiversity Baseline Survey* (ADB Loan No. 1767 SRI (SF)).

The overall aim of the Contract is to assess the current status of biological diversity within a small set of protected areas\(^2\) to inform their future management, using sound and practical scientific methods that can be repeated over time and applied more widely by the Department of Wildlife Conservation to other protected areas under its remit. The Contract was implemented over the period April 2006 - March 2007.

A one-year extension to this Contract was awarded by the Ministry of Environment & Natural Resources, primarily to enable three additional protected areas\(^3\) to be surveyed and further sampling to be conducted in Ritigala and Wasgomuwa during the wet season. This Extension has been implemented by Infotechs Ideas (Pvt) Ltd, in association with Greentech Consultants (Pvt) Ltd, during the period October 2007 - October 2008. Of particular relevance to this Field Manual are the following three objectives in the Contract:

- Establish firm baseline data for future monitoring of biological diversity and develop survey protocols for use in the inventory of the biota of Sri Lanka.
- Establish sound repeatable field sampling methodologies that are appropriate and topical for local conditions.
- Establish rigorous methods of collection and management of data and voucher/reference specimens from the selected protected areas. Where possible, collect duplicate reference specimens for lodging with other Sri Lankan national facilities that curate natural history material, particularly the National Herbarium.

A key output of this Contract is the establishment of a centralised biodiversity facility at the National Wildlife Training Centre, Giritale, where specimens and records arising from the Biodiversity Baseline Survey are accommodated and integrated within a computerised database system that is linked to the Department of Wildlife Conservation’s server in Colombo.

The following **six taxonomic groups** were selected for purposes of the Survey on the basis of being (a) well known and of general interest to scientists and managers; (b) relatively easy to survey systematically and identify; and (c) potentially of value to protected areas management:

- **Mammals**
- **Birds**
- **Amphibians**
- **Reptiles**
- **Freshwater fish**
- **Vascular plants**

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\(^2\) Horton Plains, Peak Wilderness, Ritigala and Wasgomuwa

\(^3\) Bundala, Minneriya and Uda Walawe
Purpose and content of this field manual

The purpose of this Field Manual is to document how the Biodiversity Baseline Survey was undertaken in order that the same methods can be repeated for future monitoring purposes and extended to other protected areas. It is intended for use by field workers undertaking such surveys, as well as by protected area managers to help them appreciate the basis and value of such work.

The Manual documents the design of the Biodiversity Baseline Survey and methods used for sampling the different taxonomic groups. In addition, it describes how the field data are electronically stored and managed within a Biodiversity Information Management System and illustrates how they can be analysed, using examples from protected areas covered by the Survey. It also provides details about the preservation and curation of plant and animal specimens and lists essential equipment required in the field and for curation purposes.

While the methodology has been designed specifically to support the work of the Department of Wildlife Conservation, potentially it has a much wider application both within Sri Lanka and elsewhere.

It should be noted that the manual documents the methodology prescribed for the Biodiversity Baseline Survey in the Implementation Plan and, therefore, presents the ideal. In practice, it was not always possible to achieve the ideal due to lack of equipment, inclement weather conditions or limited time with the result that sampling intensities sometimes fell short of targets. This is an inevitable part of implementing any survey design in the field and can be accommodated in the analysis of the field data, provided such shortcomings are properly and transparently documented.

The final section of this Manual outlines a framework for more rapid surveys of biodiversity for long-term monitoring purposes, based on experience from this Biodiversity Baseline Survey and the much earlier National Conservation Review of biodiversity in the country’s remaining natural forests.

In the knowledge that some users of this Manual may wish or need to know more about sampling and monitoring biodiversity, including a wide range of other census techniques, some key sources of additional information are provided at the end of the reference list.
2. SAMPLING BIOLOGICAL DIVERSITY

Introduction

Biodiversity can be appraised at three levels – genetic diversity, species diversity and ecosystem diversity. Species diversity, as measured by inventories, is the ‘stock in trade’ for selection of areas for conservation, many management decisions, nearly all environmental impact assessments and most political discussions on biodiversity. While surrogates may be found for defining ecosystem diversity (such as forest types or vegetation associations) and genetic diversity is more frequently described only for larger charismatic or economically important species, diversity at the species level invariably underpins discussions of biodiversity in both scientific and public debates.

Description of species diversity is generally confined to well researched groups, such as vascular plants and larger vertebrates with little attention given to the remaining 99% of biodiversity (Ponder and Lunney, 1999) that is made up of non-vascular plants, fungi, invertebrates and micro-organisms. The completeness of inventories compiled for these frequently monitored charismatic groups are greatly influenced by scale, with global or continental diversity generally well described by species richness (Myers et al., 2000), regional or landscape diversity is less well described (Orrock et al., 2000; Gomez de Silva and Medellin, 2001) and local diversity often poorly described (How, 1998; Thompson et al., 2003).

Questions concerning the derivation, accuracy, adequacy and interpretation of inventories are a central issue for consideration in determining the relevance of species lists to the conservation and management of biological resources.

Sampling considerations

An understanding of the strengths and limitations of the methodology employed to generate species inventories is essential to their interpretation. Methodologies vary enormously, particularly between plants which are sedentary and animals which are mobile to varying degrees. Plant species richness is usually determined or counted in absolute terms with all individuals, species or assemblages in an area measured in totality, while animal species richness can only be estimated by one of several approaches that take into account the movement or behaviour of the specific group being assessed.

Vertebrate groups, which represent the ‘charismatic’ taxa that form the majority of the faunal species inventories currently available for biodiversity assessment, all require different sampling methodologies. Thus, inventories should only be interpreted after taking into account:
- methodological constraints with respect to the taxonomic group being assessed;
- timing and duration of the survey; and
- expertise of the recorders in identifying the taxa and their experience with the methodologies.

Timing, duration and replication of sampling

The distribution and abundance of most faunal species varies temporally in relation to daily, seasonal or longer-term cycles or fluctuations in their environments. This variation reflects on the genetic diversity of species as well as the diversity of communities of which they form a part. Thus, sampling of the different faunal groups should be undertaken at times of day or night and during seasons of greatest activity. In the case of plants, sampling is best done during the flowering seasons or, at least, avoiding the driest times of year, to facilitate the ready identification of species.

Shortcomings in interpreting these temporal variations are compounded by the fact that different responses may be expected in different ecoregions where driving environmental variables, such as day-length, rainfall and temperature, operate at different times and scales. Frequently, biodiversity surveys are of such short duration that less than 50% of the total assemblage is recorded and this percentage is generally highly skewed in favour of the more common species (How, 1998).
In assessing species diversity it is essential that consideration be given to variation in activity and
distribution over sampling time. There are no ‘hard and fast’ rules concerning the number of
replicates needed to accurately assess variation but 35 replicates per sampling unit of classification
has been shown to be necessary to generate precise and unbiased estimates of diversity evenness
indices (Payne et al., 2005).

**Expertise**

An additional constraint applicable to species inventories relates to the expertise of the recorder. Lists
based on observation alone are subjective and have to be assessed with respect to the competence of
the observer to correctly identify the species. This is particularly relevant to birds and amphibians
where calls, behaviour and, above all, experience of the observer are crucial to the validity of the
identification.

**Inventory interpretation**

Species inventories are used in a wide variety of contexts and analysed in many different ways. As
Boero (2001) states: “Look at species lists in a standard ecological paper and check how accurate are
the data sets that, often, are analysed with the most sophisticated statistical packages”. Many
inventories are merely compendiums of information collected previously from an area and, therefore,
contain all the inherent limitations associated with the use of non-quantitative methodologies.
Inventories generated from museum or herbarium collections are cases in point. Similarly,
unwarranted emphasis is regularly placed on threatened species, for which surveys are rarely
adequate, with the result that these threatened taxa form the basis of resource allocation for species
recovery plans, weight the criteria for reserve design, constrain development or exploitation and
underpin many state-of-the-environment decisions (Possingham et al., 2002). However, for the better
known and studied taxonomic groups, such as birds and mammals, there may be sufficient historical
records by way of species inventories to identify and evaluate long-term and broad-scale changes in
the composition and distribution of the flora or fauna.

**Sampling adequacy and inventory evaluation**

The detection of faunal species is highly variable and dependent on the complex relationship between
an animal’s behaviour and its environment. Consequently, there is a high degree of variation in
determining the composition of species in faunal assemblages.

Assessments of faunal assemblages are often made using the most conservative information available -
the basic species inventory. Balmer (2002) provides evidence that analyses devoid of species’
relative abundances do not reveal the real ecological patterns in the data, based on an analysis of
assemblage differences using similarity measures that considered both species presence and
abundance. It is particularly important that analyses include species recorded only once at one or more
locations, as this may provide valuable information about rare species most at risk from threats such
as environmental change and disturbance. Many ecological packages allow for this type of analysis.

Species accumulation curves or alternative methods (Thompson et al., 2003, Smith et al., 2000,
Diserud and Aagaard, 2002, van Gemen et al., 2005), based on either sampling effort or captures,
are essential for an appraisal of the completeness of an inventory. For example, species accumulation
curves were used to identify forests which were not adequately surveyed during the National
Conservation Review, thereby highlighting the need for further sampling prior to any decisions being
taken about their future management (Green and Gunawardena, 1997). Other approaches to
determining the adequacy of inventories are based on the probability of capturing new species using
capture-recapture algorithms (Nichols et al., 1998).
The area of inventory evaluation is expanding rapidly in the literature with suggestions that auto similarity (Cao et al., 2002) and sensitivity analysis (Freitag et al., 1998) provide more accurate measures of species richness than estimates or comparisons based on sample size.

Long-term monitoring of biological diversity is expensive and rarely undertaken. However, repeated surveys provide fundamental information on seasonal, annual and other cyclical changes that cannot be obtained by alternative means. Such studies are necessary for obtaining a detailed inventory of threatened, rare or uncommon species in a location (How and Cooper, 2002).

**Alternatives to species inventories**

Umbrella, focal, indicator or keystone species (Lambeck 1997), have been proposed as surrogates to replace more time-consuming and expensive surveys to inventory entire taxonomic groups. While some of the literature on the effectiveness of these alternative approaches remains conjectural (Simberloff, 1998), it has been shown for woody plants in Sri Lanka, for example, that higher-taxon richness can be used as a surrogate for total species richness (Balmford et al., 1996a, 1996b).

The use of surrogates has been taken even further using the concept of congruence, whereby knowledge about the diversity of one taxonomic group is interpreted to reflect the diversity of other groups. MacNally et al. (2002) advise caution in using this approach, having found a lack of congruence in diversity between taxonomic groups within a specific area (i.e. high diversity in one taxonomic group does not necessarily correlate with high diversity in another). At the bioregional scale in Western Australian, taxa assemblages differ markedly according to the underlying climatic, edaphic and environmental conditions (McKenzie et al., 2000).

Finally, at regional scales, there is a new literature to suggest that species richness can be predicted from environmental variables (Trakhtenbrot and Kadmon, 2006). Such an approach has considerable attraction in terms of costs and time, with a potentially important role in informing regional policy and decision-making processes.

**Conclusions**

- Species inventories are central to the identification and description of biodiversity hotspots (Brooks et al., 2001). They play an important role in selection of areas for conservation (Cabeza and Moilanen, 2001; Margules and Pressey, 2001) and provide the basis of most environmental impact assessment protocols. However, the value of species inventories is proportional to their completeness and accuracy. These key measures are seldom highlighted in the presentation of inventories and, together with a statement of methods employed, are essential for their assessment and interpretation.

- Species inventories can be enhanced when greater emphasis is given to improving identification skills and the quality of data presented for interpretation. The practice of vouchering is desirable for most taxonomic groups as it provides: ‘hard evidence’ of the identity of the species; baseline information on species biology; and, importantly, an opportunity to evaluate species changes over time. Vouchering can involve collecting whole specimens, tissue, skin or hair samples and, as increasingly practised, accompanied by digital images.

- Species inventories are decidedly more informative if accompanied by quantitative data on species abundance, since this permits a more accurate and enhanced level of assessment of both the methodology and comprehensiveness of the inventories.

- The use of surrogates for assessing biological diversity may be helpful if resources (time and funds) are scarce but their limitations must be understood and fully acknowledged. Environmental correlates can inform assessments of biological diversity but they cannot replace detailed inventory surveys.
3. FIELD SURVEY METHODS

Biodiversity Baseline Survey protocol

The Biodiversity Baseline Survey has been designed in accordance with the following protocol, as specified in the Contract for Consulting Services of Biodiversity Baseline Survey:

- **All major habitats** in each protected area are sampled in a standard manner that is acceptable to international refereed scientific journals. The approach is designed to enable comparisons of species richness and diversity to be made between different habitats, while also providing information on the habitat preferences of individual species.

- The location of the surveys is guided by habitat maps, produced under a separate component of the Protected Area Management and Wildlife Conservation Project.

- Sampling techniques must not be destructive of any habitat or population of individuals.

- Sampling methods, while necessarily differing between taxonomic groups, must generate quantifiable, verifiable and repeatable results in accordance with the criteria specified in Box 3.

- The same staff should be used throughout the Survey to the maximum extent possible to minimise observer biases in species richness and abundance arising from differences in the competencies of field staff. Observer consistency should be checked in the field during the course of the Survey.

- In order to obtain a representative sample of species within each habitat, it is necessary to ensure that the sampling effort is adequate for each of the taxonomic groups by means of rarefaction curves. The required level of effort can be determined by examining the relationship between the cumulative number of species recorded with a habitat and the sampling effort (in terms of the number of plots or quadrats sampled or time spent sampling).

<table>
<thead>
<tr>
<th>Box 3 Criteria for sampling and collection of field data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Wherever possible, standard internationally recognized techniques will be adhered to throughout the Biodiversity Baseline Survey and clearly described in a protocol.</td>
</tr>
<tr>
<td>2. Sample sites (i.e. transects, quadrats and plots) will be permanently marked on the ground and, using GPS coordinates, on 1:10,000 maps.</td>
</tr>
<tr>
<td>3. Vertebrate groups will be surveyed in each of the selected habitats. Fish will be surveyed in at least one and preferably three streams, representative of each subcatchment, at their upper, mid and lower reaches.</td>
</tr>
</tbody>
</table>
| 4. Sampling and collecting effort should be consistent between habitats and recorded. (i.e. Effort should not be proportional to extensiveness of habitat.)

5. Voucher and reference specimens will be collected routinely; the former will always be collected in the case of any uncertainty about the identification of any taxon.

6. Animal and plant specimens will be properly prepared in the field for later preservation and fixation/mounting, all in accordance with international standards of curation.

7. All animal specimens will have the standard set of international measurements recorded and, where possible, they will be photographed while alive or shortly after death.

8. All records of specimens and observations will be georeferenced and given a unique identifier. They will be recorded on standard field data forms and transferred to a georeferenced database.

1The National Conservation Review field data form may be used as an example (Green and Gunawardena, 1997).

Habitat condition and conservation status of associated species

While the overriding purpose of the Biodiversity Baseline Survey is to inventory plant and animal diversity, it is important to record the condition of the habitat and any signs of disturbance to its integrity or that of its constituent plant and animal species. Such records may inform changes to the biological diversity recorded by subsequent monitoring.
For purposes of this Survey, the principle measures are based on the following:

- The condition of the vegetation, based on the cover abundance of the various canopy layers and any signs of disturbance (e.g. tree-cutting, collection of forest products). This is recorded while inventorying the plants.
- The quality of the water, based on such measures as biological oxygen demand and turbidity. This is recorded while inventorying the fish.
- Incidences of traps and snares set for wildlife. The presence or absence of such forms of poaching is recorded while sampling transects. Such incidences observed elsewhere in the protected area are also recorded and georeferenced.
- Intensity/frequency of fishing in the vicinity of sampling points.

Water quality is a particularly apt indicator: not only does it reflect the ecological condition and integrity of catchments but it also represents an environmental service that directly benefits local communities within the vicinity of a protected area.

**Stratified and gradsect sampling of terrestrial habitats**

Knowledge about the distribution of the different habitats within an area provides a sound basis for stratifying the design of a survey at an appropriate scale. Habitat maps were available for this purpose, having been derived from overlays of a suite of geographic and environmental variables that include geology, soil, altitude, aspect, land use and vegetation (EML, 2005, 2006a, 2006b, 2006c).

The habitats identified from these overlays are complex and numerous, as shown in Table 2 for various combinations of overlays of vegetation, altitude, slope, soil and geology. In reality, such a detailed level of classification is somewhat theoretical and could not be readily recognised or meaningfully interpreted on the ground in relation to the distribution of plant and animal communities.

**Table 2** Number of habitats for various combinations of geographic and environmental variables and river sub-basins for protected areas covered by the Biodiversity Baseline Survey

<table>
<thead>
<tr>
<th>Protected area:</th>
<th>Horton Plains 3,160 ha</th>
<th>Peak Wilderness 22,379 ha</th>
<th>Ritigala 1,528 ha</th>
<th>Wasgomuwa 29,036 ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total area:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vegetation</td>
<td>6</td>
<td>6</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Vegetation, altitude</td>
<td>n/a</td>
<td>n/a</td>
<td>10</td>
<td>n/a</td>
</tr>
<tr>
<td>Vegetation, slope</td>
<td>21</td>
<td>18</td>
<td>15</td>
<td>19</td>
</tr>
<tr>
<td>Vegetation, soil</td>
<td>26</td>
<td>23</td>
<td>n/a</td>
<td>29</td>
</tr>
<tr>
<td>Vegetation, geology</td>
<td>70</td>
<td>71</td>
<td>n/a</td>
<td>76</td>
</tr>
<tr>
<td>Vegetation, slope, soil, geology</td>
<td>n/a</td>
<td>489</td>
<td>56</td>
<td>475</td>
</tr>
<tr>
<td>Vegetation, altitude, slope, soil, geology</td>
<td>n/a</td>
<td>n/a</td>
<td>83</td>
<td>n/a</td>
</tr>
<tr>
<td>River sub-basins</td>
<td>6</td>
<td>43</td>
<td>23</td>
<td>34</td>
</tr>
</tbody>
</table>

*Excludes *Pinus* and tea plantations  
*a*Excludes paddy and gardens

For this reason, constraints in available survey time and the need to replicate sampling units to evaluate variation, it is necessary to adopt a more pragmatic and feasible approach, focusing on sampling the main vegetation types, while taking into account the spatial distribution of other environmental variables such as geology, soils, slope, altitude and streams when aligning transects, as well as roads for purposes of access. Horton Plains, for example, can be stratified into five main vegetation types, each of which can be sampled by aligning transects along the gradients of such variables (Figure 1).

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4 Other measures such as nitrates, phosphates and algal biomass are recommended but require more sophisticated equipment and analytical procedures.
This is similar to the gradsect approach used in the National Conservation Review (Green and Gunawardena, 1997). Gradscts are essentially transects aligned along environmental gradients, enabling a maximum diversity of taxa to be sampled with a minimum of effort (ref). While very cost effective for single traverses through one or more habitats, as employed for the National Conservation Review, gradscts are less suited to repeat visits for purposes of checking traps or censusing birds over consecutive time periods because of the time taken to travel their length.

Figure 1 Horton Plains - each of the main vegetation types can be sampled along transects aligned along other environmental gradients, such as slope, soil and geology, as shown diagrammatically by the two lines superimposed on the vegetation map

Quantitative integrated sampling design for terrestrial habitats

Sampling of the different taxonomic groups is quantitative and integrated in design in order to:

- ensure that measures of species richness and abundance are robust and of an internationally accepted standard;
- maximise the flexibility with which field data can be interrogated;
- make most efficient use of time, energy and other resources spent marking out transects and quadrats; and
- simplify logistics and maximise efficiencies from working together as a multi-disciplinary team.
The design is also intended to be simple rather than sophisticated, so that it can be readily applied to other protected areas and repeated for monitoring purposes by the Department of Wildlife Conservation and others engaged in such work by the Department in the future.

Box 4  Description of sampling units

**Transects – 1 km long**
Transects of 1 km in length are marked out in at least four replicates of the broadly defined habitat (i.e. vegetation) types within a protected area. They are positioned to cover, as far as discernable from available maps, a single vegetation type. In areas comprising a mosaic of highly fragmented habitats, a transect may cover more than one vegetation type and also encompass ecotones.

Where necessary or appropriate, transects may be extended from 1 to up to 4 km in order to cover several vegetation types along a major environmental gradient, such as altitude. Such transects conform to gradsects.

**Quadrats – 100 m x 5 m**
The length of a quadrat is defined for the duration of the sampling period by a centre line of highly visible nylon cord, marked at 10 m intervals by tape. A thin cane or pole 2.5 m in length is aligned perpendicular to the central cord in order to determine the width of the quadrat. Cords are removed at the end of the sampling period (four-days).

The ends of each 100 m length of quadrat line are geolocated, using a GPS (Global Positioning System), and permanently marked for purposes of future monitoring, using paint and/or a thick nylon cord tied loosely around a branch of vegetation (not applicable in grasslands).

Quadrats may be aligned along a single straight line 1 km in length, or in a square (250 m x 250 m) or rectangle (350 m x 150 m). Regardless of transect shape, quadrats must be 150 m apart. This criterion is particularly important with respect to mobile taxa, such as birds, to minimise the potential for recording the same individual in adjacent quadrats. Sometimes, where access is very restricted (e.g. either side of a footpath, as in the vicinity of Adam’s Peak in Peak Wilderness Sanctuary) or where the habitat is very linear in its distribution (e.g. bamboo in Horton Plains National Park), it may be necessary to establish four parallel quadrats, spaced at least 150 m apart.

**Plots – 10 m x 5 m**
The subdivision of quadrats into plots is critical. It enables reptile/amphibian the Quadrat Clearing Technique to be applied at 20 m intervals, small mammal traps to be positioned at 10 m intervals and, most importantly, it provides the basis for examining potential relationships between plant and animal (amphibian, reptile or small mammal) species and assemblages.

The key design elements of this integrated, quantitative approach to sampling terrestrial taxonomic groups (i.e. not freshwater fish) are as follows, while a more detailed description of the sampling units referred to below is provided in Box 4:

- Each habitat type, as defined by vegetation type, is sampled by a minimum of four replicate **transects** of 1 km, taking into account as much of the environmental variation (notably in geology, soil, aspect and altitude) as practicable given constraints of time and access to the area. (Note: It may be necessary to increase the number of replicates, depending on the size and shape of the protected area, and its range in environmental variables.)
- **Quadrats**, measuring 100 m x 5 m, are located at 150 m intervals along 1 km transects (i.e. 4 quadrats per 1 km transect).
- Each quadrat is divided into 10 m x 5 m **plots**, within which each taxonomic group is sampled.
- Vascular plants are recorded in every plot of each quadrat; vertebrate taxonomic groups are recorded from within certain plots in either all quadrats (birds) or alternate quadrats (amphibians, reptiles, mammals). **This sampling design provides the basis for examining relationships between plant and animal species or assemblages.**
The logistic units for planning and undertaking field work are based on sampling a total of 4 km of transects within a four-day period. The duration of field sessions is governed by the minimum period of time considered necessary to effectively sample (trap) small mammals at a given location: it is considered to be four days/nights. Given that plants can be sampled at a rate of four quadrats (1 km) per day, equating to 4 km of transects per four-day period, sampling intensities for the faunal taxonomic groups were adjusted accordingly. In practice this amounts to the following sampling rates and intensities:

- **Plants**: four quadrats per day (i.e. 1 km per day)
- **Amphibians and reptiles**: five alternate plots within each of two quadrats per day (i.e. 1 km per day)
- **Birds**: two Variable Circular Plots (VCPs) at the beginning and end of each of four quadrats surveyed early morning and evening (i.e. 1 km per day)
- **Mammals**: eleven traps for small mammals (e.g. rodents) at 10 m intervals and two traps for small carnivores at the beginning and end of each of two quadrats along four transects per day (i.e. 4 km per day, repeated over four days/nights).

Note that the two quadrats sampled for mammals alternate with those sampled for herpetofauna.

The level of sampling intensity achieved during the Biodiversity Baseline Survey over a six-month period, involving a total of some 120 days in the field and based on an average of two 10-day trips per month, is summarised in Table 3 to illustrate what can be realised within such a timeframe. It is also compared with what was previously achieved during the more rapid and extensive but less intensive National Conservation Review. **It should be noted that it was not possible to cover wet and dry seasons within the six-month survey period: this is a limitation of this particular Survey.**

**Table 3** Sampling intensity achieved by the Biodiversity Baseline Survey (2006-2007) and the National Conservation Review (1991-1996)

<table>
<thead>
<tr>
<th>Protected area:</th>
<th>Horton Plains 3,160 ha</th>
<th>Peak Wilderness 22,379 ha</th>
<th>Ritigala 1,528 ha</th>
<th>Wasgomuwa 29,036 ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodiversity Baseline Survey</td>
<td>No. habitats sampled</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Total km of transects</td>
<td>20</td>
<td>20</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>No. quadrats (100m x 5m)</td>
<td>80</td>
<td>80</td>
<td>64</td>
</tr>
<tr>
<td>National Conservation Review</td>
<td>No. gradsects</td>
<td>3</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Total km of transects</td>
<td>4</td>
<td>&gt; 5</td>
<td>&gt; 4</td>
</tr>
<tr>
<td></td>
<td>No. quadrats (100m x 5m)</td>
<td>16</td>
<td>22</td>
<td>18</td>
</tr>
</tbody>
</table>

1Wasgomuwa Lot 1 only

**Quantitative sampling design for aquatic habitats**

The habitat maps for each of the four protected areas include a layer that defines river sub-basins (EML, 2005, 2006a, 2006b, 2007), examples of which are reproduced in Figure 2 for Ritigala and Wasgomuwa. These maps can be used to identify river sub-basins and plan the sampling of rivers and other water bodies. In order to maintain consistency with the survey of terrestrial habitats, a minimum of four replicates should be sampled within each river sub-basin. The level of sampling intensity achieved during the Biodiversity Baseline Survey is summarised in Table 4.

**Table 4** Sampling intensity of sub-basins achieved by Biodiversity Baseline Survey (2006-2007)

<table>
<thead>
<tr>
<th>Protected area:</th>
<th>Horton Plains 3,160 ha</th>
<th>Peak Wilderness 22,379 ha</th>
<th>Ritigala 1,528 ha</th>
<th>Wasgomuwa 29,036 ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. sub-basins</td>
<td>6</td>
<td>43</td>
<td>23</td>
<td>34</td>
</tr>
<tr>
<td>No. sub-basins sampled</td>
<td>2</td>
<td>14</td>
<td>6</td>
<td>16</td>
</tr>
</tbody>
</table>

1provisional figures only
Sampling methods

The sampling methods used to quantify the diversity of the different taxonomic groups, together with information about the intensity of sampling, are described and summarised in Table 5. In addition, a various other methods can be used, as opportunities and time permit, to supplement species inventories with more qualitative information. These methods are described in Table 6. The relationship between transects, quadrats and plots are illustrated diagrammatically in Figure 3, and various layouts of transects for different terrain in Figure 4. Further details about the different methods are provided below under the respective taxonomic group.

Vascular plants

Quantitative: All vascular plant species are recorded on a plot-by-plot basis (10 m x 5 m) within every quadrat (100 m x 5 m) of a transect. The number, estimated height (with the exception of climbers) and DBH (Diameter at Breast Height) of individuals exceeding 5 cm DBH is also recorded. Any herbaceous species within a quadrat is recorded as present (but individuals are not counted).

Qualitative: The presence of additional species encountered along a transect, between quadrats, is recorded separately. Any other additional species encountered elsewhere within the protected area are also recorded.

Voucher specimens: Specimens of unidentifiable, previously unrecorded or otherwise notable species are collected, photographed as appropriate, curated and subsequently lodged at the National Wildlife Training Centre, with duplicates provided to the National Herbarium, Peradeniya.
Table 5  Survey methods and minimum sampling intensity used for the Biodiversity Baseline Survey to quantify biological diversity of the different taxonomic groups

<table>
<thead>
<tr>
<th>Taxonomic group</th>
<th>Method: description</th>
<th>Traps/plots/quadrats</th>
<th>Minimum sampling intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No./km transect</td>
<td>No. replicates/habitat</td>
<td></td>
</tr>
<tr>
<td>Vascular plants</td>
<td>100m x 5m quadrats: located at 150m intervals along 1km transect.</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Amphibians and reptiles</td>
<td>Plot clearing (daytime): 5 plots (5m x 5m) cleared in each of 2 quadrats (100m x 5m)</td>
<td>10 plots</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Plot clearing (night time): 1 plot (20m x 5m) cleared in single quadrat (100m x 5m).</td>
<td>1 plot</td>
<td>4</td>
</tr>
<tr>
<td>Birds on land</td>
<td>Variable Circular Plots: 8 VCPs (radius = 0-10m, 11-20m and &gt;20m) aligned at each end of 4 quadrats (100m x 5m): birds recorded for 10 minutes within each VCP, once at dawn and once at dusk.</td>
<td>8 VCPs</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Direct observations: record birds along 1 km transects between quadrats.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birds on water</td>
<td>Total counts: for discrete water bodies, using one or more locations from which to record birds, as appropriate.</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Birds</td>
<td>Mist nets: 2 nets (at canopy and ground levels) manned by 2 persons during daytime (6 am – 6 pm) at appropriate location adjacent to transect.</td>
<td>2 mist nets</td>
<td>4</td>
</tr>
<tr>
<td>Bats</td>
<td>Mist nets: 2 or 4 nets (at canopy and ground levels) manned by 2 persons for ≥3 hours at 6.30-11 pm in close proximity to transect.</td>
<td>2 or 4 mist nets</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Mist nets: 2 or 4 nets (at canopy and ground levels) manned by 2 persons for ≥3 hours at 6.30-11 pm along selected waterholes, streams, trails and near roosts.</td>
<td>2 or 4 mist nets</td>
<td>4</td>
</tr>
<tr>
<td>Small mammals</td>
<td>Sherman traps: located at 10m intervals within 2 quadrats (100m x 5m) for 4 nights.</td>
<td>22 traps</td>
<td>4</td>
</tr>
<tr>
<td>Larger mammals</td>
<td>Tomahawk traps: located at each end of 2 quadrats (100m x 5m), for 4 nights.</td>
<td>4 traps</td>
<td>4</td>
</tr>
<tr>
<td>All mammals</td>
<td>Direct observations: along 1 km transects, where possible recording perpendicular distance from transect to mammal sighted or spoor.</td>
<td>1 km, variable width</td>
<td>4</td>
</tr>
<tr>
<td>Freshwater fish</td>
<td>Water quality: pH, conductivity, dissolved oxygen, total dissolved solids, turbidity, temperature recorded at head, mid- and lower reaches of rivers.</td>
<td>n/a</td>
<td>4 per subcatchment</td>
</tr>
</tbody>
</table>
Table 6  Additional survey methods to be used as appropriate

<table>
<thead>
<tr>
<th>Taxonomic group</th>
<th>Method: description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vascular plants</td>
<td><strong>Between quadrats</strong>: additional species recorded as present.</td>
</tr>
<tr>
<td>Amphibians and reptiles</td>
<td><strong>Visual encounters</strong>: along roadsides, footpaths and by water bodies, both daytime and at night. No. individuals and search time recorded.</td>
</tr>
<tr>
<td>Birds</td>
<td><strong>Opportunistic observations</strong>: record species along ecotones (e.g. roadsides) while travelling to and from field.</td>
</tr>
<tr>
<td>Bats</td>
<td><strong>Bat detector</strong>: record relative abundance of bats.</td>
</tr>
<tr>
<td>Mammals</td>
<td><strong>Road counts</strong>: direct and indirect observations along roads/tracks travelled on foot or by vehicle early morning, towards dusk and with flashlights at night.</td>
</tr>
<tr>
<td></td>
<td><strong>Waterhole counts</strong>: total counts of individuals daytime and with flashlights night-time.</td>
</tr>
<tr>
<td>Freshwater fish</td>
<td><strong>Nets</strong>: range of fish nets and traps, rod and line, electro-fishing and snorkelling used to catch or fish in streams and water bodies. Number of individuals and sampling effort recorded.</td>
</tr>
</tbody>
</table>

**Amphibians and reptiles**

**Quantitative**: Amphibians and reptiles (herpetofauna) are sampled by clearing 5 m x 5 m areas of alternate plots within alternate quadrats of a transect. (Note: the other two quadrats are assigned to sampling mammals.) The method, known as the Quadrat Clearing Technique (Heyer et al., 1994), depends on thoroughly clearing the ground and searching the vegetation layers, the latter to within vertical distances that can be reached to catch and identify specimens. Litter is cleared, logs are rolled over and soil and litter are raked. The Quadrat Clearing Technique is also used at night to sample a single area of 20 m x 5 m within one quadrat per transect.

**Qualitative**: The presence of additional species encountered along a transect, between quadrats, or elsewhere within the protected area is recorded separately. Visual Encounter Surveys (Heyer et al., 1994) may be carried out at night, with a similar amount of time spent searching each habitat over the survey period.

**Voucher specimens**: Specimens of unidentifiable, previously unrecorded or otherwise notable species are collected, measured in accordance with international standards, photographed, curated and subsequently lodged at the National Wildlife Training Centre, with duplicates of rare or potentially new species being deposited at the National Museum.

**Birds**

**Quantitative**: Variable Circular Plots (VCPs) are established at the beginning and end of each quadrat within a transect to record birds directly or indirectly from their songs over a period of 10 minutes in duration, once early morning and once in the evening. The distance from the observer is recorded, based on three radial zones (0-10 m radius, >10-20 m radius and > 20 m radius). The VCP is divided into quarters, each of which is recorded for 21/2 minutes. Any bird seen or heard outside the quarter being monitored is record as outside. Similarly, birds observed while travelling along a transect between VCPs are recorded as outside. Previous studies in tropical forests have shown that at least 50 VCPs per location are required to provide a representative sample of birds within an area.

5 Such equipment was not available for the Biodiversity Baseline Survey.
Each transect is 1 km in length

Each transect has four 100m x 5m quadrats at 150m intervals

Each quadrat has a VCP at its beginning and end, with 3 bands (0-10m, 10-20m, >20m)

Figure 3 Location of quadrats within a transect and Variable Circular Plots within a quadrat. Quadrats A and C are sampled for mammals, quadrats B and D for reptiles (not to scale).

Figure 4 Transects are aligned in a single line (a), in parallel (b, d) or in a square, depending on the distribution of the habitat, access to it and sampling logistics. They should also be aligned perpendicular to environmental gradients, such as altitude (b, c) to maximise sampling of biological diversity. (not to scale)
Mist nets (6, 9 and 12 m in length and 2.6 m or 3 m in height) are used to sample cryptic species that tend to be under-represented in VCPs. In practice, due to time constraints, each habitat was surveyed from only one location for 1-3 days.

**Qualitative:** The presence of additional species encountered elsewhere within the protected area is recorded separately. Also, total counts are made at discrete water bodies from one or more recording stations as necessary, preferably on more than a single occasion.

**Voucher specimens and tissue:** In general, it is not necessary to collect specimens as most birds caught in a mist net (or by other means) can be readily identified in the field by an expert. However, the opportunity should be taken to photograph netted birds. Additionally and if possible, samples of tissue (notably feathers) should be taken, suitably preserved and deposited with a national DNA reference collection.

**Mammals**

**Quantitative:** Small mammals are sampled using 11 small aluminium box traps (Sherman or Elliott), set 10 m apart within alternate quadrats of a transect for four consecutive nights. (Note: the other two quadrats are assigned to sampling amphibians and reptiles.) The period of trapping and baits used for this Survey were based on previous experience in Sinharaja (Wijesinghe and Brooke, 2005; Wijesinghe, 2006). Traps are baited with roasted coconut and checked and reset early each morning. Larger ‘Tomahawk’ traps, for catching medium-sized carnivores, such as civet and mongoose, are positioned at the beginning and end of each quadrat and baited with dry fish. Bats are trapped using mist nets (12 m by 2.5 m) set at ground level and canopy height in close proximity to a transect for one or two nights.

Direct observations are made along transects, where possible recording perpendicular distance from the centre line to the location of a sighting. Arboreal species are recorded whenever observed.

**Qualitative:** The presence of additional species encountered elsewhere within the protected area is recorded separately. Also, water bodies are surveyed for bats, using mist nets.

**Voucher specimens and tissue:** Captured specimens of small mammals, including bats are measured, in accordance with international standards, photographed, curated and subsequently lodged at the National Wildlife Training Centre, with duplicates of rare or otherwise interesting species deposited at the National Museum. In the case of medium or larger sized mammals, samples of tissue should be taken prior to their release, suitably preserved and deposited with a national DNA reference collection.

![Figure 5 Tomahawk (left) and Elliott (right) traps for small carnivores and rodents, respectively](image)
Freshwater Fish

Quantitative: Replicate sampling of the head, mid- and lower reaches of at least four rivers or streams within each sub-basin of a protected area is undertaken for fish and various measures of water quality. Other large water bodies, such as wewas and swamps, are similarly sampled where accessible. Fish are sampled using sweep, throw, gill and seine nets, rod and line, and by snorkelling for a standard period of time, or until it is apparent that additional species are unlikely to be recorded from the sampling station.

Water quality is assessed for pH, conductivity, dissolved oxygen, total dissolved solids, turbidity and temperature at sampling stations.

Qualitative: It is sometimes advisable to employ professional fishermen to use throw nets in deeper water bodies and tanks. Endeavours should be made to sample diurnally (daytime and at night). The presence of species reliably reported by fisherman may also be recorded, separately from field data.

Voucher specimens and tissue: Specimens of fish are measured, in accordance with international standards, photographed, and a selection of them preserved for subsequent identification and curation. They are subsequently lodged at the National Wildlife Training Centre, with duplicates of rare or otherwise interesting species deposited at the National Museum.

Resource requirements

Personnel

Competent and experienced field biologists, with a sound understanding of survey design and sampling methodology and expertise in the taxonomy of one or more plant or animal groups being recorded, are a prerequisite for undertaking baseline surveys. Such persons should also be experienced in the use of survey equipment, such as Global Positioning Systems, as well as trapping and curation techniques with respect to their area of taxonomic expertise.

Expertise is required in the design and development of information management systems for the storage, analysis and retrieval of field data. It is also required for the analysis, interpretation and presentation of information on biological diversity.

A list of posts and periods of engagement necessary for undertaking this Survey is provided in Annex 1. The total resource input amounted to some 230 person months.

Equipment

Equipment used to undertake this Survey and considered essential is listed in Annex 2. Much of this is available locally but certain items either have to be or are best imported from overseas. Several months may be required to order and purchase the necessary equipment and this must be completed ahead of the field programme.

It should be noted that all georeferencing of sampling locations was made using Global Positioning System (GPS) recorders that were set on the Kandawala datum for Sri Lanka.
4. COLLECTING AND PRESERVING SPECIMENS

Legal and ethical considerations

Legislation

The collection of plant and animal specimens from the field must be in accordance with the relevant national legislation and protocols. This includes obtaining the necessary licenses or permits from the appropriate authorities.

The Fauna and Flora Protection Ordinance provides for the protection, conservation and preservation of Sri Lanka’s biological diversity within national reserves (defined as including strict natural reserves, national parks, nature reserves, jungle corridors, refuges, marine reserves and buffer zones) and sanctuaries. Thus, the hunting, killing, wounding and collecting of any wild animal is prohibited in national reserves and in any state land within sanctuaries. Similarly, the felling, girdling, lopping, tapping, burning, damaging and collecting or removal of any plant is prohibited.

In the case of areas outside national reserves and sanctuaries, the wild vertebrate fauna is protected from the above activities except for those mammals and reptiles, birds, amphibians and fish listed in Schedules I, II, III and IV, respectively (i.e. species listed in these Schedules are not protected). The invertebrate fauna within such areas is protected if it is listed in Schedule IVa. In the case of plants, any species listed in Schedule V or protected tree listed in Schedule VI that is growing on private or public lands outside national reserves and sanctuaries is protected from the above activities.

Under Section 55 of the Ordinance the Director may authorize the collection of specimens for a national museum (or zoo) or university.

Ethics

It is also important to observe relevant ethical codes. In general, specimens should be collected sparingly and treated carefully to avoid damage and potential wastage. If very few individuals of a species are encountered or likely to be encountered, then only a single specimen should be collected from a given locality. Vertebrate species should be trapped, handled and killed humanely, conforming to internationally accepted standards and practices. In the case of mammals, for example, there are guidelines approved by the American Society of Mammalogists (1998). Further details are included in the sections below.

Plants

Herbarium Specimens

A herbarium specimen is a pressed plant sample deposited for future reference. A voucher specimen must be deposited in a recognized herbarium committed to long-term maintenance. It supports research work and may be examined to verify the identity of a specific plant used in a study. Identifications are subject to change as plant classification is continuously changing in the light of new evidence. Vouchers specimens help cross-reference these changes to previous research.

Pressing and drying plant specimens

Specimens are pressed in a plant press, which consists of a wooden frame (for rigidity), corrugated cardboard ventilators (to allow air to flow through the press), blotting paper (to absorb moisture) and folded newspaper (to contain the plant material). The plant press is tightened using straps with buckles or bolts with wing nuts. The objective of pressing plants is to extract moisture from the plant
in the shortest period of time, while preserving its morphological integrity, and to yield material that can be readily mounted on herbarium paper (an acid-free cardstock) for long-term storage.

A plant specimen should be pressed flat to no more than 11 x 16 inches in order to fit on a standard herbarium sheet. If the specimen will not fit those dimensions, it may be folded or cut into sections. Multiples of smaller plants may be pressed together in order to provide ample material for mounting and study. Small loose pieces, such as seeds, may need to be placed in a small paper packet inside the newspaper. Large fruits or bulbs are often cut in half lengthwise or in slices prior to pressing. In order to insure rapid and thorough drying, extremely succulent materials such as cactus stems may need to be sliced open and some of the fleshy interior scraped out.

Each specimen should comprise a stem with attached leaves and, if at all possible, flowers and/or fruits. The roots of herbaceous plants should also be included. In the case of very large trees, shrubs, or vines, pieces should be selected to illustrate to the greatest extent possible the overall characteristics of the plant and the range of variation in flowers, leaves, and other structures. Each collection of a plant specimen(s) should be assigned a collection number. Data for each collection should be entered in a field notebook for subsequent inclusion in the specimen label (see below). If ample material is available, a minimum of three specimens should be pressed for each collection, especially if collecting from a region where the flora is poorly known. This will help facilitate the identification of the plants through the distribution of specimens to various herbaria and researchers. An ethical collector will insure that their collecting activities do not pose a significant threat to the survival of rare or endangered species and habitats.

Care should be taken to make good specimens. Pressing material immediately upon collection produces the best specimens. Samples that are allowed to wilt prior to pressing will generally prove to be inferior specimens. Plants should be carefully arranged as they are placed in the press to maximize preservation of diagnostic features. Leaves, flowers, and fruits should be spread out so that they do not overlap and can be observed from different perspectives. The collection number should be clearly written on the outside of the newspaper containing each plant specimen. The plant press must be kept tight; this prevents shrinkage and wrinkling of the plant material and yields specimens that are easier to mount securely on herbarium paper.

The pressed plants must be thoroughly dried prior to storage and mounting. Best results are obtained with the use of an electric drier that holds the presses and provides steady bottom heat between 95°F and 113°F. A low ambient humidity and good airflow around and through the presses also insures rapid and thorough drying of plant material. As the specimens dry, it may be necessary to further tighten the straps on the press to minimize shrinkage and wrinkling. Rapid drying promotes the best retention of plant colour, but excessively high temperatures or long drying periods can result in blackened, discoloured, and brittle specimens.
Mounting and storage of specimens require a considerable financial commitment in the form of archival materials, labour, and storage cabinets. Herbaria have the prerogative not to accept specimens if the cost of labour/materials for processing is excessive or if the quality of specimens or accompanying data is unsatisfactory. Due to differences in mounting methodologies and materials, most herbaria prefer not to accept specimens already mounted. As plant classification is generally based on the morphology of flowers and fruits, in most cases sterile (non-flowering/fruiting) specimens will not be accepted.

**Preserving specimens in the field**

Specimens labelled with collection numbers are placed between folds of newspaper and a number are compressed and tied together in convenient-sized bundle, which is then inserted into a heavy gauge liquid-proof polythene bag. About 1 litre of 75-80% industrial methyl alcohol is sprinkled inside. The open end is then folded and also sealed. The alcohol fills the bag as vapour, preserving the contents for weeks.

**Identification of plant specimens**

The identification of plant specimens requires considerable time and effort. It involves a thorough literature review consultation with herbarium personnel on previous or ongoing research on the flora of the region. The identification of unknown plant material is accomplished with the use of dichotomous keys; published plant descriptions, illustrations and photographs; and comparison with properly identified herbarium specimens. A microscope is essential for the observation of many diagnostic features.

Regulations pertaining to collecting plants vary from country to country and state to state, so it is important to make official contacts well in advance. It is customary and may be required for one full set of specimens to be deposited in a herbarium of the host country or state.

When submitting a plant specimen for identification, it is critical that the sample includes flowers and/or fruits and a portion of the stem with at least several leaves attached. Information about a plant's growth habit, size, colour, fragrance and its habitat can often assist with the identification process. When submitting photos for identification include full-frame close-ups of foliage, as well as flowers or fruits. Each photo should include a scale (e.g. a ruler or coin). Photos should be accompanied by the same descriptive information provided with a pressed specimen.

**Herbarium specimen labels**

A plant specimen must be accompanied by a label on which relevant field data are accurately recorded, as summarised in Box 5. An example of a plant specimen label, as used for the Biodiversity Baseline Survey, is provided in Annex 3.
Mounting herbarium specimens

Mounting is the process of affixing a dried, pressed plant and its label to a sheet of heavy paper. This provides physical support that allows the specimen to be handled and stored with a minimum of damage. Prior to attachment, the specimen and its label are laid out on the paper to allow maximum observation of diagnostic (usually reproductive) features, as well as the range of variation in vegetative structures, including both sides of the leaves. Plants are generally arranged in a life-like position (i.e. roots or lower stem toward the bottom of the sheet and flowers toward the top).

Space must be left on the sheet for the specimen label, annotation labels and institutional accession seal. A paper envelope or packet should also be attached to the sheet to contain any fragments of the specimen that break off over time.

Once the optimum arrangement of the specimen has been determined, it is attached to the sheet using a combination of glue and strips of gummed linen cloth tape. Glue is used sparingly to attach the larger portions of the plant, such as stems, large leaves, and fruits. Gummed linen mounting strips are then applied to reinforce portions of the plant that might be torn loose as the specimen is used. Large or bulky items may need to be sewn onto the sheet with a sturdy linen thread. The objective is to secure the specimen firmly to the mounting paper, while leaving some pieces of the plant loose enough to be removed if necessary. Excessive applications of glue that embed flowers and seeds on the sheet may make it impossible to observe diagnostic features or to remove samples, thus rendering the specimen useless for scientific study.

Box 5  Herbarium specimen labels

**Scientific name:** genus, species, authority, subspecific information

**Determiner:** name of the person who identified the scientific name of the plant

**Location:** details to include country, state or province, county or municipality and a description of the location with reference to roads, road junctions, mile markers and distances from cities and/or towns. Latitude and longitude (preferably taken with a Global Positioning System), section, township and range, and elevation may also be helpful. Such information is used by researchers to map the distribution of species at a variety of scales and using GIS computer application.

**Habitat:** the type of plant community from where the plant has been collected and, if known, other plants growing in association.

**Plant habit:** the form of the plant (e.g. tree, shrub, vine, herb) and its height, for example: tree, ca. 50 ft; sprawling herb.

**Abundance:** described in terms of the frequency with which a plant is recorded in the collection/survey area: rare, occasional, frequent or common.

**Plant description:** characteristics of the plant which may be lost upon drying, such as flower/fruit colour and fragrance, leaf orientation and aroma.

**Collector name:** this may include the names of others present with the collector.

**Collection number:** a sequential, straightforward numbering system (1, 2, 3, ...) is preferable but it may be desirable to precede this by a name or alphanumeric code that identifies a particular survey or project.

**Date of collection:** a format with the month spelled out or abbreviated and 4 digit year should be used to prevent ambiguity (e.g. 3 May 2003 and not 3/5/03 or 5/3/03).
All supplies used for mounting must be both archival and durable. Archival denotes materials that are free of acids and other compounds that may cause them or the specimen to degrade or discolour over time. Consequently, the mounting paper, label paper, packet paper, ink, glue, mounting strips and storage folders should all be acid free and designed for long-term stability.

**Animals**

Most of the larger museums and universities that maintain preserved collections of vertebrates have curators trained in approved methods of preparing and maintaining an alcoholic collection. However, many other professional institutions and individuals have an interest in natural history and a desire to preserve specimens but lack knowledge of the proper techniques. The following guidelines should be to be of help for such situations when specimens need to be adequately labelled, well preserved, and fixed in a standard position. Steps for the curation of specimens for collections are as follows:

- **Euthanasia** Specimens should be euthanized in a humane way that will leave them relaxed and undamaged.

- **Fixing and preservation** While the specimens are still relaxed, they should be arranged in trays or containers so that they will harden in the proper position. Liquid fixatives or preservatives must be introduced into the body cavity, limbs and tail, either by hypodermic injection or through slits.

- **Labelling** Each specimen should be accompanied by specific and essential data, either attached directly or entered in a notebook with a number corresponding to a numbered tag tied to the specimen.

- **Storage** After specimens have been fixed in the proper position, they should be stored in liquid preservative for at least several days, after which they may be allowed to remain in the liquid, or transferred to plastic bags for temporary storage.

**Euthanasia**

Vertebrates all require different euthanizing techniques. **Reptiles and mammals** of any size are best euthanized by hypodermic injection with dilute sodium pentobarbital. If this is not available then chloroform or ether can be used to induce terminal anaesthesia. Death should be quick, often within a few seconds. Injection should be made either into or near the heart for rapid action. Reptiles can also be killed by immersion in warm water (45° C) for a few minutes. Turtles may require somewhat warmer water or longer periods of immersion. Small mammals can also be asphyxiated by running car exhaust fumes into a plastic bag containing the animal.

The most satisfactory method of euthanizing **amphibians** is by immersion in a solution of chlorobutanol (Hydrous). Euthanizing solution may be prepared by dissolving one level teaspoon of powder in a gallon of water. Specimens should be placed in a container and completely immersed in the solution. If the solution is fresh the specimens will die in a few minutes; if it is old, more time will be required. A very dilute (about 10%) solution of ethyl alcohol is also an effective killing agent.

**Fixing and preservation**

If specimens are to be made permanently immune to decomposition, it is necessary for liquid fixative to be introduced into the body cavity, limbs and tail within as short a time (preferably less than an hour) as possible after the animals have been killed. Specimens should be hardened by fixation in a position that will facilitate their use. The mouth of shrews and bats should be open, and the body should be reasonably straight. The abdominal cavity should be slit open and the diaphragm cut to ensure rapid and complete fixation. Animals larger than small squirrels may require injection with a hypodermic syringe. The most satisfactory and least destructive to the specimen is by injection.
Specimens are usually fixed in 10% buffered formalin as soon as possible after death. This procedure is important for histology. Small mammals usually need to fix for about 48 hours, or until they have become hard from the formalin. After fixation is complete, the specimens are rinsed in water until they are free of formalin and then transferred to alcohol (ethanol).

Specimens should be preserved preferably in 70% alcohol. After rinsing the formalin from them, they should be transferred to 75% alcohol. Water from the specimens will dilute the alcohol to about 70%. To prevent the alcohol from being diluted too much, a bottle should be filled with specimens to no more than 50-65% of its volume before adding the alcohol.

Occasionally, specimens may be fixed directly in ethanol. In this initial fixation, specimen crowding is critical because the alcohol is diluted by the volume of each fresh specimen added to the container. The volume of the specimens should not exceed half the volume of alcohol. A simple way to maintain this standard is to fill empty containers to slightly more than two thirds of their volume and then add specimens until the container is filled.

Formalin Ideally, formalin should be used for injecting and fixing specimens. Formalin is the commercial name of a solution of formaldehyde gas (CH\textsubscript{2}O) in water. It is available from chemists at a strength of from 38% to 40%. A strength of 10% formalin is best for most purposes. If the original strength is 40%, it should be mixed at a ratio of nine parts of water to one part formalin. Formalin may also be used as a preservative. Its advantages over other preservatives are: it is inexpensive; it is generally available and a small bulk of concentrated stock solution may be diluted as needed; and specimens almost never decay in it. Its principal disadvantages are: it has a very irritating odour; it is very poisonous and may cause skin irritation or rash; it has a tendency to make specimens become brittle if the solution is too strong; certain colours tend to fade rapidly; and it must be stored in rustproof containers. (Buffering of the 10% solution is recommended as formalin is slightly acidic. One buffering system that may be used is a mixture of monobasic and dibasic sodium phosphate, comprising 13 grams/gallon of monobasic and 24 grams/gallon of dibasic).

Ethyl alcohol Ethanol is usually sold at a strength of 95% (190 proof). For injection and fixing it should be used at full strength. For subsequent preservation and storage of vertebrates it should be used in the proportion of 3 parts of 95% ethanol to 1 part of water. Ethanol that has been stored in open containers loses its strength rapidly due to evaporation. Its strength may be tested with an alcoholometer.

Labels and records

Specimens without data are of little or no scientific value. It is very important that each specimen is accompanied by certain specific information. This information may be either printed on a label attached to the specimen or recorded in a notebook. If a notebook is used, the information should be identified by a unique number; a tag bearing the same number should be attached to the specimen. The following data should accompany each specimen:

- The **locality** from where the specimen was collected, including the geographic reference either in latitude and longitude or distance and direction from a named feature, city or town which can be found easily on a map. The name of the county and state, province, district or other corresponding political unit, should be included. Altitude may be extremely important: if not readily ascertainable from maps of the area, it should be recorded. With the widespread availability of relatively inexpensive Global Positioning System (GPS) receivers, it is easy to obtain precise latitude, longitude and altitude data in the field.

- The **date of collection**, with the month written out or abbreviated clearly (i.e. 29 Aug. 2006). Do not use numbers separated by dashes (e.g. 8-5-56) as that can easily lead to confusion in the information.

- The **name of the collector** should be recorded.
In addition to these data, it is desirable to make careful descriptions of colour and pattern before individuals are killed, since colour often fades rapidly after death. If a field notebook is used a description of the habitat, climatic conditions may be provided, together with notes on behaviour, such as the voice of calling birds or amphibians, or a reference to an audio taped call. If numbered field tags are used, a notebook should be kept in waterproof ink or soft pencil, in which each number is listed consecutively, accompanied by the above data.

Specimens should be labelled using tags made especially for this purpose or using the best grade of "bond" or linen paper. Tags made of laminated paper or cardboard will fall apart in liquid. Write only with a medium-soft pencil, never with ordinary ink, ball point pen or indelible pencil. "India Ink" or "Higgins Eternal Black" or Engrossing Ink may be used, but the tags should not be immersed in liquid until the ink is completely dry. An example of an animal specimen label, as used for the Biodiversity Baseline Survey, is provided in Annex 3.

Storage

After the specimens have been fixed by injection or via slits for the requisite time and tagged, they should be put directly into preservative. If they are to be transferred later to plastic bags for temporary storage or to be shipped, they should first be allowed to remain completely immersed in preservative for at least 48 hours if formalin is used or a week if alcohol is used. The longer they are allowed to stay in preservative, the better. They should be loose and completely covered with plenty of liquid. Specimens which have been hardened in trays should also be allowed to soak in preservative for a day or two before being shipped or placed in plastic bags for storage.

If space is no problem, preserved specimens are best kept in glass containers. Bail-top jars with a glass top and rubber gasket are best. Jam, coffee and other jars with a metal screw top lid may be used but should be carefully watched for rust and evaporation. Glass jars with polyethylene lids and liners are more commonly used in collections, since they are easier to obtain than the traditional bail-top jars and their lids form a tight seal. Metal containers should be used only for temporary storage, unless coated on the inside with paraffin or some other rustproof material.

Maintaining specimens and records

There is an obvious requirement to maintain collections in a sustainable way so that there is no or negligible deterioration of the specimen or loss of information associated with it. Specimens should be checked regularly to ensure that they continue to be in the correct state of preservation, at least annually in tropical conditions. An electronic database of specimen information should be created and kept up to date with information on new accessions. It should be regularly backed up and the copy of the information should be held securely at a separate location.

Identification

The identification of specimens, particularly plants and some of the smaller vertebrate groups and most invertebrates groups, may require considerable taxonomic expertise that is beyond the knowledge and experience of the field researcher, even with the help of taxonomic field identification guides and keys. Such expertise should be sought to ensure that specimens are correctly identified.

Some of the main guides and keys for the identification of taxonomic groups covered by the Biodiversity Baseline Survey are listed at the end of the references.
5. MANAGING THE FIELD DATA

This section addresses management of field data in the context of the methods and process, and the technology considerations that underpinned the development of a Biodiversity Information Management System. It provides a preview of the developed application and considers its further development for potential future applications as a tool for managing information on biological diversity.

It should be noted that this section is not a “How To Use” guide to the application of the database. Such information is documented separately (De Silva, 2007a, 2007b).

5.1 Methods and process

Field data need to be captured electronically, cleaned, and made ready for further analysis. The processes are very simple and involve: recording data onto forms in the field, from which they are transposed into electronic, pre-defined spreadsheets (Figure 6); and loading master datasets into the database system for subsequent analysis and reporting (Figure 7).

![Diagram](image)

**Figure 6** Diagram showing transposition of field data from forms to pre-defined electronic spreadsheets. These may be collated into the back office computer, from which the relevant printouts are obtained for checking and correction. Alternatively, an electronic copy of the spreadsheet is provided to the relevant field person for checking and correction.
Figure 7 Diagram showing loading of verified field data into the database for analysis and reporting. Depending on the format of electronic spreadsheets, in certain instances the operator may have to re-cast the data in a specific format.

5.2 Technology considerations

In order to arrive at an affordable and proven technology application, the following should be considered:

- **Cost effectiveness** The application must have the capability of being rolled out cost effectively to any team associated with surveys of this nature.
- **Ease of use** The application must be extremely user friendly, with facilities to filter, sort, import, and export data. Further, the look-and-feel of the application must be easily assimilated by users familiar with a Microsoft Office environment.
- **Extensibility** The application must be extensible, with the need for a minimum of specialised IT staff (and skills) to cater to future requirements.
- **Flexibility** The application must be flexible, both in terms of usage and future enhancements, without the need for major modifications to its core structure.
- **Maintainability** The application must be easily maintainable to provide added features and enhancements.
- **Operability** The application must be available to users with relatively low computing power at their disposal to easily run the application. In other words, the application should not demand excessive computing resources (e.g. power, storage) or special software.
- **Resources** The application must be developed given the current level of project IT resources (and budget) available.
- **Robustness** The application should be written in general code to provide robust software that can accommodate a wide range of requirement, thereby avoiding the need to insert extra code just to handle special cases. This application rides on commercial-grade database software.
The application should have security features that can be enabled as required by its administrator. User management and data protection is of prime importance.

Microsoft Windows and Microsoft Office are currently available on most PC and laptop computers being used within Government and private sectors in Sri Lanka. Further, when computers are purchased, the base price includes Microsoft Windows and Microsoft Office.

Hence, the identified technology is Microsoft Office 2003, with Microsoft Windows as the operating system. Microsoft Excel is used for the electronic spreadsheets and Microsoft Access for the database and user interface.

5.3 Application overview

The application, named the Biodiversity Information Management System, comprises four major sections as follows and shown in Figure 8:

- **Master data** This section maintains a list of projects (such as the Biodiversity baseline Survey), details of their respective team members, the locations (e.g. protected areas) surveyed by the project and the respective geo references and habitat types for each of the sampled quadrats or, in the case of fish, water bodies. It also holds species lists for each of taxonomic groups, together with information on endemicism and threat status.
- **Field transect data** These are the records of plants and animals observed in quadrats of respective transects. In the case of fish, the records relate to freshwater sampling points.
- **Field opportunistic data** These are the records of plants and animals observed opportunistically within the survey location.
- **Species accumulation graphs** These can be generated for each taxonomic group within a location for one or more transects and habitats. This facility provides an indication of the comprehensive of the survey in terms of capturing the full complement of species diversity within a given habitat or location (see Section 6.1).

Figure 8 Opening window of the Biodiversity Information Management System developed for the Biodiversity Baseline Survey
Importantly, the application is designed to support any number of surveys of biological diversity within the same or different locations.

### 5.4 Future opportunities

The Biodiversity Information Management System provides the Department of Wildlife Conservation and its managers of individual protected areas with a powerful tool for comparing and combining survey data in order to develop a comprehensive understanding of the status and distribution of plant and animal taxa within individual and networks of protected areas.

The application, in its current phase of development, has the necessary infrastructure and ‘plumbing’ to accommodate the following:

- Export of data to the Department’s IT system for further analysis, such as using a Geographic Information System.
- Import of new datasets for the Department’s own purposes, including the storage, management and analysis of data.
- Deployment of the application at desired locations for research and education purposes.
- Distribution of the application to *bone fide* researchers for the purpose of gathering survey data.
- Tailoring as required for specific purposes, with minimal investment in IT resources and skills.
6. **ANALYSING THE RESULTS**

The types of analyses applied to a biodiversity sampling regime depend entirely on the objectives of the study, the methodologies used and the data collected and available for analyses (see Sections 2 and 3). For the purposes of the Biodiversity Baseline Survey, data analysis was undertaken in the following sequence:

(i) Data were checked for various recording and entry errors.
(ii) The effectiveness of sampling was assessed using species accumulation curves.
(iii) Species diversity was measured using both Alpha and Beta statistics.
(iv) Observed species diversity was interpreted in the areas of interest.

**Data screening**

Data screening is a basic process that is vital for all biological survey work. At best, analyses are worthless if the data used are incorrect. At worst, it is wasteful of time and, more critically, can lead to completely erroneous conclusions upon which management or policy decisions may be based. Such outcomes must be avoided at all costs.

It is essential, therefore, that all data are checked for errors. It is highly likely that, initially, faulty data will be incorporated in the database. There are many possible ways in which this can happen, for example: incorrect coding of sites; miss-spelling species names; recording numbers incorrectly, leading to outliers; and erroneous data entry.

The value of subsequent analyses is dependent upon the veracity of the data used. Thus, it is vital that every effort is made to ensure the database information is carefully checked before beginning the full analysis. Many techniques can be used, but two-way tables (matrices) of species by quadrat or habitat type, containing the numbers of individuals, is one very effective way. Simple graphs of an equivalent nature to these tables are also very helpful.

**Data appraisal - assessing effectiveness of sampling**

The first step in data appraisal, after screening and verifying the data, is to evaluate the number of species recorded in relation to the effort expended in encountering them. The effort expended can be measured by the number of individuals encountered, the number of units sampled or the time taken (e.g. number of days). A graph of the cumulative number of species encountered plotted against effort provides a species accumulation or discovery curve that enables an investigator to assess the relative completeness of the sampling regime.

Some examples of species accumulation curves are provided below in Figure 9. These plots show the cumulative number of species recorded (Y-axis) against the sequential number of individuals observed or collected (X-axis). Poorly sampled assemblages will continue to show a steep incline in the number of species encountered as sampling effort increases, while a well sampled assemblage will show a distinct plateau in the cumulative number of species with additional sampling. Neither graph in Figure 9 suggests sampling has been adequate. However, plants appear closer to reaching a plateau than birds, suggesting the former have been better sampled, although more effort is required for both.

Caution should prevail in the analysis and interpretation of data from locations that are poorly sampled for their composite species assemblages. In situations where there is no evidence of any plateau in the cumulative number of species, further sampling is necessary. If this is not possible because of lack of time or other resources, **it is imperative that the inadequacy of the sampling is highlighted in all analyses and reports generated from the Biodiversity Information Management System to ensure that any management and policy decisions take account of this constraint.**
Figure 9 Examples of species discovery curves for plants (left) and birds (right) in various protected areas, based on records from the Biodiversity Baseline Survey.

There are also several predictive models available for estimating the potential number of species in a defined sampling unit that are based on the functions of the number of species seen in only one or two samples (Chao2, Jacknife), the number of species that have only one or two individuals in the entire pool of samples (Chao1), or that set the proportions of samples that contain each species (Bootstrap). These estimates are available in ecological packages such as Primer-E (Clarke and Warwick, 2001) and EstimateS (Colwell, 2005). The Chao2 and Bootstrap models were used during the extension to the Biodiversity Baseline Survey to estimate the potential number of species in each habitat sampled, as well as the number likely to occur in all surveyed habitats, combined, within a protected area.

Species diversity

The core analyses of any conservation study are the estimates of biological diversity. A sample often comprises subgroups, referred to here as units, such as particular localities, regions or habitat types. As a consequence, two levels of diversity are commonly recognised and employed:

- **Alpha diversity** is the diversity within a unit.
- **Beta diversity** is the amount of compositional variation between units.

**Alpha [α] diversity**

The best known measurement of diversity within a unit is Species Richness (S), which is the number of species in the unit. It is an intuitive and well-established measure that is widely used by field ecologists because of its simplicity and ease of calculation. It is also readily appreciated and easily communicated to colleagues, decision makers and the general public.

However, there is a wide and growing literature on other measures of diversity that have appeal because they are less dependent on sample size or effort and take into account the distribution of species’ abundances in the unit under consideration. The generality and applicability of such measures have been evaluated by Jost (2006) and his recommendations have been followed in the extension to the Biodiversity Baseline Survey by adopting two indices of Alpha diversity, in addition to Species Richness. These are calculated as follows, using the program Primer-E (Clarke and Warwick, 2001):

- **Shannon Entropy** \((H')\) calculated from \(\exp(- \sum_{i=1}^{S} p_i \ln p_i)\), where \(p_i\) is the proportion of individuals of the \(i^{th}\) species.
- **Gini-Simpson Concentration** \( (D) \) calculated from \( \frac{1}{\sum_{i=1}^{S} D_i^2} \).

Pielou’s evenness index \( [J' = H' / \log(S)] \) was also used to examine cases where species richness and diversity indices were not in accord.

It is clear from plots of these three measures of alpha diversity in all seven habitats surveyed at Wasgomiwa National Park, for example, that Species Richness is correlated with both diversity indices in all cases except grassland. Furthermore, both species diversity indices \( (H' \text{ and } D) \) are strongly correlated (Figure 10). Comparisons of alpha diversity provide a valuable means of assessing the relative conservation importance of different units (e.g. protected areas, habitats, transects).

![Figure 10](image-url) **Figure 10** Measures of alpha diversity in Wasgomiwa National Park, using Species Richness \( (S) \), Shannon Entropy \( (H') \) and Gini-Simpson Concentration \( (D) \). Dry-Mixed Evergreen Forest \( (DMEF) \) is classified into dry, intermediate and wet types.

**Beta \([\beta]\) Diversity**

Beta diversity quantifies the amount of compositional variation and relationships between units of interest, such as habitats within a locality. There are numerous ways of measuring beta diversity that are dependent on concepts or measurements of underlying sources of compositional variation (see Magurran, 2004).

A widely-used measure, the matrix of the Bray-Curtis coefficient of similarity, was calculated for purposes of the Biodiversity Baseline Survey, (see Ludwig and Reynolds, 1988; McCune and Grace 2002). As information in similarity matrices is usually very difficult to understand, various analytical procedures are used to assist with interpretation, usually by means of graphical representations. Principal Coordinates Analysis (known by several other names including ordination, metric scaling, seriation and multi-dimensional scaling) was adopted during the initial stage of the Biodiversity Baseline Survey, using the statistical package Genstat (Genstat, 2006). Subsequently, in the extension to the Project, similarity matrices were examined with non-parametric Multi-dimensional Scaling,
using the ecological package Primer-E (2007). Both of these approaches present the similarity matrix in two (or more) dimensions. The relative advantages of the latter are discussed by Clarke (1993).

An example of non-parametric Multi-dimensional Scaling, shown in Figure 11, reveals some important features of floristic data collected from Peak Wilderness Sanctuary. First, Submontane Forest quadrats fall into two distinct sub-groups, indicating this may be a heterogeneous habitat type. Secondly, there are two sub-groups of Lowland Forest, one of which is similar to Disturbed Lowland Forest quadrats. Thirdly, Montane Forest appears similar to one of the Submontane Forest sub-groups but caution should be exercised because these two sub-groups may actually differ on a third axis. Finally, Secondary Submontane Forest quadrats, although represented by only four samples, are quite widely spread, suggesting that they may constitute a heterogeneous group.

![Figure 11](image)

**Figure 11** Multi-dimensional scaling ordination of woody plant quadrats at Peak Wilderness Sanctuary, based on square-root transformed species abundance data and Bray-Curtis similarity matrix. Each point represents a quadrat. The low Stress value of 0.09 indicates that the two dimensional plot provides a good approximation of the distances between quadrats, in terms of similarity in species composition.

**Interpreting diversity**

No single index of diversity adequately depicts species diversity within a given unit. However, there is generally a strong correlation between all indices once sample sizes become large. This highlights the importance of extensive sampling. For purposes of the Biodiversity Baseline Survey, Species Richness (S) has been used as a key indicator of diversity.

A detailed appraisal of the design of the Survey indicated that the selection of four 1-km long transects to represent each of the major habitat types, defined in terms of vegetation types from the habitat maps (EML 2005, 2006a, 2006b, 2006c), was an oversimplification. Most transects were found to traverse two or more defined habitats once sited on the ground. Habitat patterns were a mosaic in nearly all protected areas: sampling at the transect level generally cut-across habitat boundaries and mosaics. Consequently, the major analyses were performed at the quadrat level of sampling unit in relation to habitat type. Outliers in the analyses were reviewed with respect to the level of disturbance or other modifying processes (e.g. timber extraction, fire or modified soil profiles) that might explain deviations from expected species composition, patterning and relationships. Finally, comparisons were made between the habitat types in all surveyed protected areas.
7. MORE RAPID SURVEYS FOR MONITORING BIODIVERSITY

This section has been added to the Field Manual in the wake of experience gained from implementing the original one-year Biodiversity Baseline Survey and a one-year Extension to the project. The Extension has provided the opportunity to undertake baseline surveys in an additional three protected areas (Bundala, Minneriya and Udawalawe national parks), as well as to revisit Ritigala Strict Natural Reserve and Wasgomuwa National Park in the wet season. One of the objectives of the Extension is:

3. To develop and pilot a more rapid biodiversity survey methodology, based on accumulated BBS experience, which can be applied in the immediate future to other protected areas under DWC’s authority to inform management planning.

The need to consider a more rapid biodiversity survey methodology to monitor biodiversity in protected areas is driven by relatively high investments in time and money of the current approach. By extrapolation of the total investment (US$ 1,085,000) and time taken to survey seven protected areas (two months per site using a field team of 15 persons), it is estimated that it would require at least a further US$10 million to survey the entire protected areas system under the jurisdiction of the Department of Wildlife Conservation and one team of 15 persons would take 10 years to complete such a task.

Thus, a more strategic approach, accompanied by a more rapid survey methodology, is required to generate baseline information that can be used to monitor changes in biodiversity over the longer term. This is developed in the light of experience gained from the Biodiversity Baseline Survey and also earlier experience from the National Conservation Review.

Learning from experience

Biodiversity Baseline Survey (2006-08)

The merits and some of the disadvantages of the Biodiversity Baseline Survey methodology, from a rapid survey perspective, are as follows:

- **The method is quantitative and sampling is integrated for terrestrial taxonomic groups**, which are recorded from the same quadrats to enable relationships between different taxonomic groups to be analysed, particularly with respect to relationships between fauna assemblages and flora associations.

- **Most extensive, quantitative data is obtained from terrestrial quadrats by sampling plants (woody) and birds.** Over 10,000 records of woody plants and over 15,000 records of birds were obtained for the Biodiversity Baseline Survey of seven protected areas, as compared with some 1,300 records for mammals, 700 for reptiles and 400 for amphibians (Table 7). The majority of mammal records (55%) were indirect observations, based on tracks, droppings and other signs (Table 8).

- **Mammal trapping is very labour intensive and time-consuming**, requiring traps to remain in the same location for a minimum of four consecutive days and inspected at least once each day. A comparison between sampling effort and trapping/misting success in Table 8 shows that there is a 1.4% chance of catching a small mammal in a Sherman’s trap on a given night and a 2.1% chance in the case of a larger mammal in a Tomahawk trap. Mist netting is a little more productive, with a 21% chance of catching a bat per hour of mist netting. In terms of direct observations, trapping and mist netting did contribute about as many records (21.5% of total records) as sightings (22.1%). Moreover, there is very little overlap between the composition of species trapped/netted and that of species sighted. Species trapped/netted but not sighted and positively identified during quadrat sampling included murids (rats and mice), shrews, civets and bats. Thus, trapping is relatively unproductive from a rapid survey perspective, albeit essential for purposes of inventorying small mammal diversity within an area.

---

6 The exceptions are herpetofauna and mammals, which are sampled along the same transects but from alternate quadrats to minimise potential disturbance to mammals from clearing plots in search of herpetofauna.
Clearing 5 m x 5 m plots, using the Quadrat Clearing Technique, to search for amphibians and reptiles is also time consuming and relatively unproductive. For example, no herpetofauna were recorded in 66% of 160 plots at Bundala, 63% of xx plots at Horton Plains, 79% of 240 plots at Minneriya, 66% of XX plots at Peak Wilderness, 68% of 235 plots at Ritigala, 55% of 240 plots at Uda Walawe and 66% of 280 plots at Wasgomuwa during the Biodiversity Baseline Survey (DWC, 2007a, 2007b, 2008a, 2008b, 2008c, 2008d, 2008e). Indeed, more information on herpetofauna diversity was often generated from opportunistic searching, including night time observations. In Ritigala, for example, 26 of the total inventory of 76 herpetofauna species were recorded in plots and 71 species were encountered opportunistically (DWC, 2008c).

The fish sampling method is also quantitative and includes measurements of water quality. Taken together, fish diversity and water quality measures are particularly valuable as landscape-scale indices, providing indicators of the health of the catchment. Approximately 1,300 records were obtained for fish (Table 7) and these include abundance data for individuals netted. Given the opportunity to monitor landscape, using water quality and fish diversity as indicators, the investment in surveying aquatic habitats is considered appropriate, especially given the socio-economic dependencies of many local communities on rivers and tanks for water and fish.

Table 7 Number of records of taxa sampled within terrestrial quadrats (mammals, birds, herpetofauna and plants) and at aquatic sites (fish) during the Biodiversity Baseline Survey (2006-2008)

<table>
<thead>
<tr>
<th>Taxon</th>
<th>Bundala</th>
<th>Horton Plains</th>
<th>Minneriya</th>
<th>Peak Wilderness</th>
<th>Ritigala</th>
<th>Uda Walawe</th>
<th>Wasgomuwa</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mammals</td>
<td>242</td>
<td>75</td>
<td>305</td>
<td>62</td>
<td>105</td>
<td>289</td>
<td>221</td>
<td>1,299</td>
</tr>
<tr>
<td>Birds</td>
<td>2,947</td>
<td>731</td>
<td>3,448</td>
<td>1,325</td>
<td>1,358</td>
<td>3,572</td>
<td>2,040</td>
<td>15,421</td>
</tr>
<tr>
<td>Reptiles</td>
<td>133</td>
<td>63</td>
<td>92</td>
<td>30</td>
<td>118</td>
<td>147</td>
<td>141</td>
<td>724</td>
</tr>
<tr>
<td>Amphibians</td>
<td>45</td>
<td>173</td>
<td>85</td>
<td>76</td>
<td>5</td>
<td>16</td>
<td>14</td>
<td>414</td>
</tr>
<tr>
<td>Fish</td>
<td>67</td>
<td>10</td>
<td>279</td>
<td>80</td>
<td>129</td>
<td>273</td>
<td>480</td>
<td>1,318</td>
</tr>
<tr>
<td>Plants</td>
<td>434</td>
<td>1,410</td>
<td>1,630</td>
<td>1,301</td>
<td>2,426</td>
<td>1,222</td>
<td>2,141</td>
<td>10,564</td>
</tr>
</tbody>
</table>

Table 8 Comparison between sampling effort and number of records of mammals within quadrats obtained during the Biodiversity Baseline Survey (2006-2008)

<table>
<thead>
<tr>
<th>MAMMALS</th>
<th>Bundala</th>
<th>Horton Plains</th>
<th>Minneriya</th>
<th>Peak Wilderness</th>
<th>Ritigala</th>
<th>Uda Walawe</th>
<th>Wasgomuwa</th>
<th>Totals</th>
<th>% Total records</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. quadrats</td>
<td>32</td>
<td>40</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>56</td>
<td>320</td>
<td>14.9%</td>
</tr>
<tr>
<td>No. trap nights</td>
<td>1,408</td>
<td>1,760</td>
<td>2,112</td>
<td>2,112</td>
<td>2,112</td>
<td>2,112</td>
<td>2,464</td>
<td>14,080</td>
<td></td>
</tr>
<tr>
<td>No. mist net hours</td>
<td>256</td>
<td>320</td>
<td>384</td>
<td>384</td>
<td>384</td>
<td>384</td>
<td>448</td>
<td>2,560</td>
<td></td>
</tr>
<tr>
<td>Total no. records</td>
<td>242</td>
<td>75</td>
<td>305</td>
<td>62</td>
<td>105</td>
<td>289</td>
<td>221</td>
<td>1,299</td>
<td></td>
</tr>
</tbody>
</table>

1 Sherman traps for small mammals (e.g. small rodents and shrews)
2 Tomahawk traps for small carnivores (e.g. civets and mongooses) and large rodents (e.g. squirrels)
National Conservation Review (1991-96)

The National Conservation Review, introduced in Section 1.4, to survey biodiversity in Sri Lanka’s remaining natural forests provided the basis of the methodology used for the Biodiversity Baseline Survey. It was undertaken at a national scale by three teams of 5-6 persons that surveyed over 200 forests during the five and a half year project. Each team comprised a botanist and zoologist, supported by assistants. The method is quantitative and rapid, and focuses on integrated sampling of woody plants and a range of vertebrate and invertebrate groups within 100 m x 5 m quadrats aligned at 150 m intervals along environmental gradients, such as altitude.

Table 9  Comparison between the National Conservation Review and Biodiversity Baseline Survey of the number of species recorded in quadrats (100 m x 5 m). N is the number of quadrats sampled.

<table>
<thead>
<tr>
<th>Taxon</th>
<th>Bundala</th>
<th>Horton Plains</th>
<th>Minneriya</th>
<th>Peak Wilderness</th>
<th>Ritigala</th>
<th>Udawalawe</th>
<th>Wasgomuwa</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCR N=05</td>
<td>N=16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mammals</td>
<td>8</td>
<td>7</td>
<td>11/07</td>
<td>8</td>
<td>10</td>
<td>14</td>
<td>19</td>
</tr>
<tr>
<td>Birds</td>
<td>20</td>
<td>26</td>
<td>27/13</td>
<td>31</td>
<td>39</td>
<td>34</td>
<td>48</td>
</tr>
<tr>
<td>Reptiles</td>
<td>2</td>
<td>4</td>
<td>4/02</td>
<td>12</td>
<td>7</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Amphibians</td>
<td>0</td>
<td>7</td>
<td>3/00</td>
<td>9</td>
<td>2</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Plants - woody</td>
<td>35</td>
<td>79</td>
<td>85/72</td>
<td>256</td>
<td>119</td>
<td>74</td>
<td>155</td>
</tr>
<tr>
<td>BBS N=64</td>
<td>N=80</td>
<td></td>
<td>N=96</td>
<td>N=96</td>
<td>N=96</td>
<td>N=96</td>
<td>N=112</td>
</tr>
<tr>
<td>Mammals</td>
<td>23</td>
<td>12</td>
<td>27</td>
<td>7</td>
<td>26</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Birds</td>
<td>140</td>
<td>42</td>
<td>126</td>
<td>64</td>
<td>74</td>
<td>135</td>
<td>95</td>
</tr>
<tr>
<td>Reptiles</td>
<td>18</td>
<td>5</td>
<td>21</td>
<td>10</td>
<td>22</td>
<td>18</td>
<td>22</td>
</tr>
<tr>
<td>Amphibians</td>
<td>8</td>
<td>13</td>
<td>10</td>
<td>16</td>
<td>4</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Plants - woody</td>
<td>60</td>
<td>77</td>
<td>107</td>
<td>105</td>
<td>135</td>
<td>95</td>
<td>158</td>
</tr>
</tbody>
</table>

a16 quadrats were sampled in Minneriya-Giritale Nature Reserve and five quadrats in Minneriya-Giritale Sanctuary during the National Conservation Review.
bWoody plants of less than 10 cm Diameter at Breast Height were not recorded in the NCR.
cWoody plants of less than 5 cm Diameter at Breast Height were not recorded in the BBS.

Some key differences between the two survey approaches of relevance to rapid biodiversity surveys are considered briefly below:

- The overall objectives of the two surveys were somewhat different, that of the National Conservation Review being to define a national system of conservation forests in which . . . forest biodiversity is fully represented . . . and that of the Biodiversity Baseline Survey being to establish firm baseline data for future monitoring of biological diversity . . . Thus, comprehensive inventory of biodiversity in so far as practicable was required to meet the objective of the former but not necessarily the latter, which is focused on identifying and, through adaptive management, responding to changes in biodiversity as appropriate.
- The National Conservation Review was designed to inventory as many species as practicable in as short a period of time as possible, given that it was undertaken at a national scale. This was attempted by a combination of stratifying the survey area and gradsect sampling, the latter being to align transects along environmental gradients to maximise the recording of species richness and diversity within as short a distance and period of time as possible. The Biodiversity Baseline Survey was intended to inventory biodiversity more intensively, especially the vertebrate fauna which was systematically sampled using a range of techniques specific to each taxonomic group.
- Interestingly, comparison of the more extensive, less intensive sampling of the National Conservation Review with the less extensive, more intensive sampling of the Biodiversity
Baseline Survey shows that the former was often as effective as the latter for recording species richness in the case of woody plants, despite sample sizes being 8-44% smaller and woody plants of less than 10 cm DBH not being recorded (Table 9). This is due, most likely, to compromises made in the alignment of quadrats for the Biodiversity Baseline Survey in order to reduce distances covered and, therefore, survey time, particularly given the need to check mammal traps daily (see Figure 4). Thus, environmental gradients were not as rigorously sampled in the Biodiversity Baseline Survey as in the National Conservation Review.

- As expected, many more species of amphibians, reptiles, birds and mammals were recorded in quadrats by the Biodiversity Baseline Survey as compared with the National Conservation Review due to the greater sampling intensity and taxon specific techniques (e.g. small mammal traps) deployed in the former (Table 9). While this clearly demonstrates the values of such techniques for inventorying biodiversity as comprehensively as possible, it does not necessarily justify their use for monitoring purposes.

**Objectives and criteria**

Clear objectives and criteria need to be defined at the outset of undertaking baseline surveys for purposes of monitoring biodiversity. These will be different to surveys that focus on inventorying biodiversity as comprehensively as possible within the available time, resources and other limitations.

The following set of objectives and criteria provide a framework for purposes of monitoring biodiversity:

- Measures of biodiversity should be quantifiable, repeatable and practicable in relation to available expertise, equipment, time and other resources.
- Biodiversity monitoring should be undertaken at ecosystem and species levels. The vegetation (habitat) should be monitored by means of surveys repeated at every 5-10 years. Species richness and diversity sampling should focus on common species as changes in abundance and/or distribution are more likely to be detected and their analysis will be more robust because of the larger sample sizes. Rare and threatened species tend to be more difficult to sample by virtue of their rare and/or threatened status and, therefore, may be less useful for monitoring purposes.
- A core set of measures should be used for all protected areas under the jurisdiction of the Department of Wildlife Conservation so that trends can be identified across the entire system of protected areas.
- The core set of measures should include monitoring at ecosystem and species levels. The former can be done remotely with respect to the vegetation (habitat) at approximately 10-yearly intervals, the latter more frequently. In the case of aquatic environments, which are very susceptible to changes in water quantity and quality, it may be appropriate to monitor at least every two or three years, if not annually or even seasonally.
- In addition to the core set of measures, it is entirely appropriate to focus on particular taxa for particular protected areas, using sampling techniques that are appropriate for such taxa and/or their habitats and/or certain times of year, provided such sampling is repeatable. Examples might include: road counts of sambar at Horton Plains (DWC, 2007a), waterfowl counts at lagoons in Bundala during the migratory season (DWC, 2008a), and counts of the newly discovered point-endemic species of day gecko (*Cnemaspis retigalensis*) that is relatively abundant (33 individuals recorded in 48 plots of 5 m x 5 m) at Ritigala (DWC, 2008c).
- Criteria should be defined as part of the management planning process, so that monitoring is timely, focused on informing management about the status of biodiversity with a protected area, and achievable in terms of available resources.

**More rapid field survey protocol**

The above review of experience gained from the present Biodiversity Baseline Survey and earlier National Conservation Review provides a basis for defining a more rapid approach to sampling biodiversity for monitoring purposes. This is outlined below:
The survey area should be stratified according to the main habitat/vegetation types and sampled by means of aligning transects along environmental gradients (e.g. geology, soil, slope, aspect, altitude and proximity to water).

A minimum of four replicates should be sampled within each habitat/vegetation type, each replicate comprising 4 quadrats (100 m x 5 m) aligned at 150 m intervals along a 1 km transect, as adopted by both the Biodiversity Baseline Survey and the National Conservation Review (see Figure 4a). Transects should be aligned along environmental gradients and may be several kilometres in length, depending on the extent of the habitat type and the environmental gradients. Transects should not be aligned in squares, as sometimes practiced in the Biodiversity Baseline Survey (see Figure 4c), because this is likely to reduce the rate of accumulation of species richness over a given distance.

Surveys should focus on sampling a core set of taxa, namely woody plants and birds in terrestrial habitats and fish in aquatic habitats using the methods described in Section 3.6 of this Field Manual. Thus, woody plants > 5cm DBH are enumerated within each quadrat (100 m x 5 m) and birds counted using VCPs located at the beginning and end of each quadrat. Sightings and signs of mammals within quadrats are also recorded systematically. Plants, birds and mammals encountered between quadrats are recorded but treated as opportunistic observations. Fish are sampled and water quality measured from the head, mid- and lower reaches of at least four streams or rivers within each sub-basin and from at least four different locations within water bodies such as tanks and lakes.

This core dataset may be supplemented by survey data for other taxa as determined by time, management priorities and available expertise and equipment. Thus, for example, herpetofauna, freshwater crabs, butterflies and molluscs may be recorded provided this does not detract from the rapidity with which the survey is undertaken. In other words, sampling of terrestrial faunal taxa should be accomplished within the time taken to sample woody plants and no longer. In practice, it should be possible to sample at least four quadrats per day in Wet Zone rain forest and up to eight quadrats in Dry Zone forest, where woody plant species richness is significantly lower.

This more rapid approach can be carried out by a small integrated team of 5-6 individuals, comprising one field botanist, one field ornithologist, who is also skilled in identifying mammals from tracks and other signs, one field fish/aquatic biologist and several field assistants.

It should be emphasised that this protocol is not a substitute for more comprehensive inventorying of biodiversity, rather it provides a basis for rapid, long-term monitoring to detect changes in biodiversity.

**Working in partnership**

While the above approach goes some way towards defining how the Department of Wildlife Conservation might address its challenge of monitoring components of biodiversity within its protected areas by focusing on a minimum set of taxa that will produce a maximum set of data, the task remains well beyond its capacity and resources to implement comprehensively in the near future and perhaps even over the next ten years. This same challenge is shared by many wildlife conservation agencies around the world; it is not peculiar to the Government of Sri Lanka but it is particularly pressing in the light of Sri Lanka being one of 34 global hotspots for biodiversity (see Section 1.4).

It is imperative, therefore, to work in partnership with other institutions, such as secondary and tertiary educational establishments, museums, conservation non-governmental organisations, local communities and also that part of the private sector which derives an income from nature-based tourism. Engagement with all of these sectors not only enables the task to be addressed more quickly and cost-effectively but it also provides a huge educational opportunity for students, researchers and others interested in biodiversity conservation. Most importantly, a partnership approach raises interest, understanding and support in biodiversity conservation among other sectors.
There are many ways of working in partnership but, given the long-term nature of monitoring, the Department of Wildlife Conservation should explore stewardship opportunities, particularly among educational institutions and local communities. This could involve a commitment to take on the role of surveying and monitoring over a long term (10-20 years), with some technical and other support facilitated by the Department. In order to progress in this direction, the Department would need to develop its small core of officers responsible for championing the wider application of the Biodiversity Baseline Survey protocol to other protected areas into a fully fledged team, with the necessary technical and managerial expertise to commission and oversee such work, as well as to develop partnerships with other bodies.
References


Sources of additional information on sampling and monitoring biological diversity


Key taxonomic references and field guides for identification of Sri Lankan flora and fauna

Plants


Fish

Amphibians and reptiles

Birds

Mammals
Composition of Biodiversity Baseline Survey team, with periods of engagement (2006-07)

<table>
<thead>
<tr>
<th>Group</th>
<th>Post</th>
<th>Duration (as specified in contract)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team Leader</td>
<td>Biodiversity Specialist</td>
<td>8 months</td>
</tr>
<tr>
<td>Database Management and Analysis Group</td>
<td>Biodiversity Analyst</td>
<td>4.5 months</td>
</tr>
<tr>
<td></td>
<td>Database Specialist</td>
<td>5 months</td>
</tr>
<tr>
<td></td>
<td>Data Entry Technician</td>
<td>10 months</td>
</tr>
<tr>
<td>Field Survey Group</td>
<td>Field Survey Coordinator</td>
<td>12 months</td>
</tr>
<tr>
<td>Field Survey Coordinator</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mammal Group</td>
<td>Group Leader</td>
<td>10 months</td>
</tr>
<tr>
<td></td>
<td>Deputy Leader</td>
<td>10 months</td>
</tr>
<tr>
<td></td>
<td>Field Assistants</td>
<td>20 months</td>
</tr>
<tr>
<td>Bird Group</td>
<td>Group Leader</td>
<td>10 months</td>
</tr>
<tr>
<td></td>
<td>Deputy Leader</td>
<td>10 months</td>
</tr>
<tr>
<td></td>
<td>Field Assistants</td>
<td>10 months</td>
</tr>
<tr>
<td>Herpetology Group</td>
<td>Group Leader</td>
<td>10 months</td>
</tr>
<tr>
<td></td>
<td>Deputy Leader</td>
<td>10 months</td>
</tr>
<tr>
<td></td>
<td>Technical Assistant</td>
<td>10 months</td>
</tr>
<tr>
<td>Fish Group</td>
<td>Group Leader</td>
<td>10 months</td>
</tr>
<tr>
<td></td>
<td>Deputy Leader</td>
<td>10 months</td>
</tr>
<tr>
<td></td>
<td>Field Assistant</td>
<td>10 months</td>
</tr>
<tr>
<td>Vascular Plants Group</td>
<td>Group Leader</td>
<td>10 months</td>
</tr>
<tr>
<td></td>
<td>Deputy Leader</td>
<td>10 months</td>
</tr>
<tr>
<td></td>
<td>Field Assistants</td>
<td>20 months</td>
</tr>
<tr>
<td>Unallocated National Consultants</td>
<td>Animal Curator/Field Assistant</td>
<td>5.5 months</td>
</tr>
<tr>
<td></td>
<td>Plant Curator/Field Assistant</td>
<td>5.5 months</td>
</tr>
<tr>
<td>Administration</td>
<td>Administrative Secretary</td>
<td>12 months</td>
</tr>
<tr>
<td>Total resource</td>
<td></td>
<td>232.5 months</td>
</tr>
</tbody>
</table>
List of field equipment essential for surveying biological diversity, and the collection and curation of plant and animal specimens

<table>
<thead>
<tr>
<th>Essential equipment</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Positioning System (GPS)</td>
<td>To record location + altitude of quadrats, plots and observations of flora/fauna.</td>
</tr>
<tr>
<td>Compass, with clinometer</td>
<td>Compass essential in event of no GPS signal. Clinometer to record slope.</td>
</tr>
<tr>
<td>(Altimeter)</td>
<td>Unnecessary if equipped with GPS.</td>
</tr>
<tr>
<td>Measuring tape - 50 m</td>
<td>To mark out quadrats (50 m is less cumbersome than 100 m).</td>
</tr>
<tr>
<td>DBH tape</td>
<td>To measure diameter at breast height of woody plants.</td>
</tr>
<tr>
<td>Binoculars</td>
<td>To identify plants (tree tops) and animals from a distance.</td>
</tr>
<tr>
<td>Digital camera</td>
<td>Use for taking images of species observed, specimens and quadrat habitat s.</td>
</tr>
<tr>
<td>Plant press</td>
<td>Use for preparing and transporting plant specimens from the field.</td>
</tr>
<tr>
<td>Spotting scope + tripod</td>
<td>To identify/count birds or large mammals from distance.</td>
</tr>
<tr>
<td>Mammal traps</td>
<td>Use Elliott or Sherman for small mammals and Tomahawk for small carnivores.</td>
</tr>
<tr>
<td>Mist nets + aluminium poles</td>
<td>To trap birds and bats. (Note: harp traps also good for bats but more expensive.)</td>
</tr>
<tr>
<td>Cloth bags</td>
<td>For handling small mammals once trapped.</td>
</tr>
<tr>
<td>Protective clothing</td>
<td>Gloves for handling small mammals.</td>
</tr>
<tr>
<td>Q beam portable lights</td>
<td>Use for night inventory/census work; especially good for large mammals.</td>
</tr>
<tr>
<td>Headlamps and torches</td>
<td>Use for night transect and opportunistic surveys, especially for herpetofauna.</td>
</tr>
<tr>
<td>Water quality kit</td>
<td>To measure pH, conductivity, dissolved oxygen, total dissolved solids, turbidity and temperature. Nitrate, phosphate and algal biomass also advocated.</td>
</tr>
<tr>
<td>Fish nets</td>
<td>Use range of sweep, throw, gill and seine nets.</td>
</tr>
<tr>
<td>Vernier callipers</td>
<td>For measuring animals.</td>
</tr>
<tr>
<td>Scales and balances</td>
<td>For weighing animals.</td>
</tr>
<tr>
<td>Dissecting/veterinary kit</td>
<td>For euthanasia, tissue collection and preservation of animals.</td>
</tr>
<tr>
<td>Plastic vials and bags</td>
<td>For use in field for temporary storage and transport of specimens.</td>
</tr>
<tr>
<td>Preservation jars - various sizes</td>
<td>Use glass with sealed tops.</td>
</tr>
<tr>
<td>Herbarium sheets</td>
<td>Use for mounting plant specimens.</td>
</tr>
<tr>
<td>Euthanizing chemicals</td>
<td>Use dilute sodium pentobarbital, chloroform or ether for reptiles and mammals; and chlorobutanol (hydrous) or 10% solution of ethyl alcohol for amphibians.</td>
</tr>
<tr>
<td>Preservatives</td>
<td>Use 10% formalin and 95% ethyl alcohol for animals; and 75-80% industrial methyl alcohol for plants.</td>
</tr>
</tbody>
</table>

ANNEX 2
Specimen labels used for plants and animals in the Biodiversity Baseline Survey

**FLORA OF SRI LANKA**
*Protected Area Management and Wildlife Conservation (PAM & WC) Project:*
*Biodiversity Baseline Survey*

Scientific name: .....................................................
Family: .................................................................
Vernacular name (s): ................................................
Habitat: .................................................................
Vegetation: .............................................................
Locality: .................................................................
GPS Coordinates: ....................................................
Altitude: .................................................................
Life form: ............................................................... Height: .................
Special notes: ..........................................................
Collector(s):
B.M.P. Singhakumara,, Nalinda Peiris, Rohan Peiris, Ravi Suranga
Identified by: ..........................................................
Collection No: DWC/BBS/WG/P/.................................
Date of Collection: ..................................................

**FAUNA OF SRI LANKA**
*Protected Area Management and Wildlife Conservation (PAM & WC) Project:*
*Biodiversity Baseline Survey*

Scientific name: .....................................................
Family: .................................................................
Vernacular name (s): ................................................
Habitat: .................................................................
Location: .................................................................
GPS Coordinates: ....................................................
Collector(s): M.R. Wijesinghe, W.B. Yapa,.P.M.C. Bandara, P. Gamage, S. Indika, K. Kumara
Identified by: ..........................................................
Collection No: DWC/BBS/WG/M/.................................
Date of Collection: ..................................................