J.Natn.Sci.Foundation Sri Lanka 2011 **39**(4):303-319

RESEARCH ARTICLE

Viability status of biosphere reserves in Sri Lanka

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Revised: 28 August 2010 ; Accepted: 20 May 2011

Abstract: Viability refers to the ability of a species to persist for many generations or a community / ecological system to persist over some specified time period. The natural vegetation is the matrix in which the biological diversity at ecosystem, species and genetic levels is developed and sustained, and therefore the viability of the natural vegetation is critical for biodiversity conservation and management. There are 29 sites listed as Biosphere Reserves in Sri Lanka, including four International Biosphere Reserves (IBR), while two more sites are in the process of being proposed as IBRs. During the recently conducted Protected Area Gap Analysis in Sri Lanka exercise, the viability status for all natural vegetation sites was assessed using condition, area and landscape criteria, *viz*, habitat condition, area, wilderness, shape and isolation. One of the most significant challenges in the application of these criteria is factoring in the large-scale changes brought about to those communities and ecological systems by anthropogenic disturbance that has occurred in the past. Satellite Remote Sensing and GIS (RS/GIS) techniques were used to assess and characterize the site viability. The sites were ranked for viability into four categories, *viz*. Very Good, Good, Fair and Poor, and colour-coded for easy reference by the conservation authorities and managers. Using RS/GIS technology, the biosphere reserves were separated from other protected areas and overlaid with the viability status map of the Gap Analysis to determine their viability. Thus, a map showing biosphere reserves that also indicates the individual viability status in four-coloured categories was generated. The final product is expected to be useful to the conservation managers for planning, prioritizing and formulating management plans for biosphere reserves in Sri Lanka.

Keywords: Biosphere reserves, gap analysis, protected areas, Sri Lanka, viability status.

INTRODUCTION

The continued existence of the focal conservation targets, such as species or ecosystems, in a given landscape depends upon maintaining the natural processes that allowed them to establish and thrive in the past. Growing concerns over the loss of biodiversity has spurred protected area managers to seek better ways of managing landscapes at a variety of spatial and temporal scales. Growing evidence that habitat fragmentation is detrimental to many species and may contribute substantially to the loss of regional and global biodiversity has provided empirical justification for the need to manage entire landscapes (Harris, 1984; Saunders *et al*., 1991). A number of developments have made possible the ability to analyse and manage entire landscapes to meet multi-resource objectives. Thus, landscape ecology involves the study of landscape patterns, the interactions among patches within a landscape mosaic, and how these patterns and interactions change over time. Landscape ecology is largely founded on the notion that the patterning of landscape elements (patches) strongly influence ecological characteristics. The ability to quantify landscape structure is a prerequisite to the study of landscape function and change. For this reason, much emphasis has been placed on developing methods to quantify landscape structure (O'Neil *et al*., 1988; Li, 1990; Turner, 1990; Turner & Gardner, 1991). Accurately calculated and simplified site viability data will be an important tool in the hands of the protected area managers for conservation, rehabilitation and management of the conservation sites.

The determination of the viability status of biosphere reserves (BRs) in Sri Lanka follows the procedure adopted in the Protected Area Gap Analysis (Jayasuriya *et al*., 2006) and involves three main steps:

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- Review of Biosphere Reserves in Sri Lanka
- Procedure for determining habitat health or habitat condition using multi-temporal remote sensing data and GIS
- Procedure for determining viability of natural sites in the context of size, condition and landscape

Review of biosphere reserves in Sri Lanka

Biosphere reserves

BRs are areas of terrestrial and coastal ecosystems promoting solutions to reconcile the conservation of biodiversity with its sustainable use. They are internationally recognized, nominated by national governments and remain under sovereign jurisdiction of the states where they are located. BRs serve in some ways as 'living laboratories' for testing out and demonstrating integrated management of land, water and biodiversity (UNESCO, 1996; UNESCO, 2002).

When the Man and Biosphere (MAB) programme was launched in 1971 by UNESCO, a natural consequence of it was to have BRs as representative samples of biodiversity conservation with a variety of natural and human-managed ecosystems as part of a larger ecological landscape unit. *An Action Plan for BRs*, which was formally endorsed by UNESCO (1984) was initially a somewhat broad concept. The BRs were suggested to have the following objectives: (a) conservation role (conservation of biodiversity at all levels from genetic to landscape); (b) research and monitoring role as part of a larger international network; (c) development role for meeting with improved quality of life for the local communities living in and around the BRs. This therefore, necessitated some degree of zoning, with a core zone, which by design should be legally protected, a buffer zone where non-conservation activities are prohibited, and a transition zone extending to the periphery where all the human population involved will consider conservation linked with sustainable development.

The BR is not an international category of protected areas; but in most cases, the BR incorporates - as its own core area - an already existing protected area. This facilitates the adoption of innovative practices in land use management in the surrounding areas, namely the buffer and the transition areas. The 'protective regimes' can be extended according to the local conditions and the current legislative frames. There is no fixed ratio between the three zones and their respective extension is expected to be adapted to the local conditions; they can be extended and reduced subsequently according to the territorial dynamics.

Until recent times, industrial human societies had assumed that natural resources are inexhaustible and is available to be exploited for human welfare. The concept of sustainable development was first articulated by the World Commission on Environment and Development (commenced in 1987), which has brought about a sharp shift in thinking on the concept of economic development. Sustainable development is now seen as that process of development aimed to meet 'the needs of the present generation without compromising the ability of future generations to meet their own needs'. Therefore, the BR concept became a testing ground for linking conservation with sustainable livelihood needs of local communities in the short-term and sustainable development of a region as part of a long-term strategy. Meanwhile, there was a distinct shift in ecological paradigm from a situation where ecosystem research kept out the humans and emphasized only on biophysical aspects, to a new situation where humans were looked at as an integral component of a socio-ecological system. Though the experiences in this direction of linking with social science research for sustainable management of natural resources still remains somewhat patchy, the concept provides a better foundation to integrate ecology in a biophysical sense with human ecology.

The international Man and Biosphere (MAB) Programme is currently coordinated and managed by the MAB Secretariat within UNESCO's Division of Ecological Sciences. The programme has considerable global coverage through its worldwide network of biosphere reserves in 107 countries, and through 142 MAB National Committees and other national focal points in 189 member states. MAB National Committees are responsible for the contribution of their respective countries to UNESCO's international MAB Programme, capacity building and information sharing, and in particular, for promoting the biosphere reserve concept.

Biosphere reserves in Sri Lanka

There are four International Biosphere Reserves or IBRs (the Sinharaja National Heritage Wilderness Area; Kanneliya-Dediyagala-Nakiyadeniya Forest Reserve; Hurulu Forest Reserve; and Bundala National Park) and 25 National Biosphere Reserves (NBRs) in Sri Lanka. Bundala International Biosphere Reserve and Kurulukele National Biosphere Reserve fall within the jurisdiction of the Department of Wildlife Conservation while all other sites are administered by the Forest Department (Forest Department, 2001). Generally, the biosphere reserves are within the legally defined categories of protected areas in Sri Lanka. These, for the most part, are relatively small forests, which nevertheless are very important for

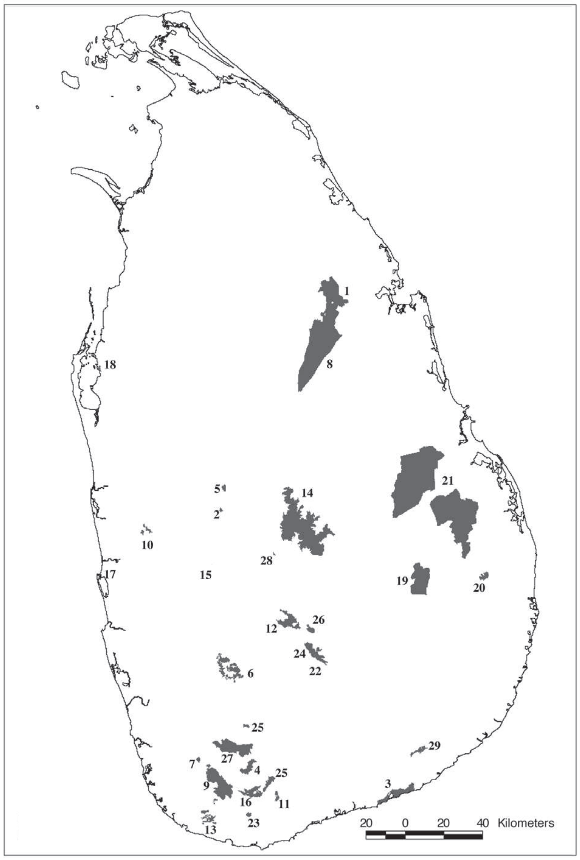


Figure 1: Biosphere reserves in Sri Lanka (refer Table 1 for details)
Source : EML Consultants Pvt.Ltd., Colombo.

the conservation of the country's endemic biota. The biosphere reserves are mapped in Figure 1 and listed in Table 1. The sites are listed alphabetically and the districts in which they are located are also given. The identification of the vegetation types follows the classification proposed by the Protected Area Gap Analysis (Jayasuriya *et al*., 2006). The areas of some biosphere reserves as given in the list provided by the Forest Department (Forest Department, 2001) differ from those given in the map of Forest Reserves and Proposed Forest Reserves. The protected area category and the administrative sector for each biosphere reserve are also indicated. With the recent survey of flora and fauna carried out in the island under the National Conservation Review Project (IUCN & WCMC, 1997), there is a need to re-examine the data from various forest sites and prepare a revised list of forests to be designated as NBRs.

METHODS AND MATERIALS

Determination of habitat health of natural forests of Sri Lanka using multi-temporal remote sensing data and GIS

The time-series information about location and condition of the vegetation cover types is one of the key elements in decision-making for management and effective conservation.

Remotely sensed data derived from satellites have been successfully utilized for decades in assessment of productivity, predicting biomass and monitoring the vegetation health status (Reeves *et al*., 2001) in temporal

Table 1: Biosphere reserves in Sri Lanka

DMEF = Dry Mixed Evergreen Forest; LWEF = Lowland Wet Evergreen Forest; MANG = Mangrove Forest; MEEF = Mid-elevational Evergreen Forest; MMEF = Moist Mixed Evergreen Forest; MOEF = Montane Evergreen Forest; SAND = Sand Dune; SAVG = Savanna Grassland; SPOF = Sparse and Open Forest (main vegetation types according to Jayasuriya *et al*., 2006).

No.	Biosphere reserve	District	Main vegetation type(s)	Extent (Ha)	Sector PA category	Biosphere status
1	Anaolundewa	Anuradhapura Polonnaruwa	DMEF, SPOF	28,957	Forest PR	National
2	Badagamuwa	Kurunegala	MMEF	213	Forest FR	National
3	Bundala	Hambantota	DMEF, SPOF, SAND	6,215	Wildlife NP	International
4	Diyadawa	Matara	LWEF, SPOF	2,447	Forest FR	National

5	Doluwakanda	Kurunegala	MMEF	400	Forest PR	National
6	Gilimale-Eratna	Ratnapura	LWEF, SPOF	4838	Forest PR	National
7	Haycock	Kalutara	LWEF	362	Forest FR	National
8	Hurulu	Anuradhapura Polonnarauwa	DMEF, SPOF	25,217	Forest FR	International
9	Kanneliya-Dediyagala-Nakiyadeniya	Galle Matara	LWEF SPOF	12,049	Forest FR/PR	International
10	Kankaniyamulla	Kurunegala	MMEF SPOF	1047	Forest FR	National
11	Kanumuldeniya	Hambantota Matara	LWEF	678	Forest FR	National
12	Kikilimana	Nuwara-Eliya	MOEF SPOF	4580	Forest PR	National
13	Kombala-Kottawa	Galle	LWEF, SPOF	1,624	Forest PR	National
14	Knuckles	Kandy, Matale	MEEF, MMEF, LWEF, SAVG, SPOF	18,290	Forest CF	National, Proposed International
15	Kurulukele	Kegalle	LWEF	9	Wildlife	National
16	Mulatiyana	Matara	LWEF, SPOF	3148	Forest FR	National
17	Munnakkara	Gampaha	MANG	51	Forest CF	National
18	Nagamadu/ Ambalam (Pubudugama)	Puttalam	MANG	245	Forest CF	National
19	Nilgala	Monaragala	SAVG MMEF SPOF	12,000	Forest	National
20	Nellikele	Ampara	SAVG SPOF	1,152	Forest PR	National
21	Nuwaragala Batticaloa	Ampara	SAVG MMEF SPOF	33,943	Forest FR	National
22	Ohiya	Nuwara-Eliya Badulla	MOEF SPOF	1,769	Forest PR	National
23	Oliyagankele	Matara	LWEF	486	Forest FR	National
24	Pattipola/ Ambewela	Nuwara-Eliya	MOEF SPOF	1480	Forest PR	National
25	Rammalakanda	Hambantota Matara	LWEF	1,406	Forest FR	National
26	Sita Eliya	Nuwara-Eliya	MOEF SPOF	713	Forest FR	National
27	Sinharaja	Galle, Matara, Ratnapura,	LWEF SPOF	11,187	Forest NHWA	International
28	Udawattakele	Kandy	LWEF	104	Forest FR	National
29	Wedasitikanda	Monaragala	MMEF DMEF SPOF	1343	Forest FR	National

Source: Forest Department (2001)

and spatial scales and proved to be economically feasible measurements (Tueller, 1989) . A wide variety of spatial analysis can be performed in geospatial domain such as point pattern analysis, network analysis, surface analysis, fuzzy analysis and forest canopy density modelling. The forest canopy density model gives a clear picture about tree canopy discrimination, however unsuccessful it is in separating bushy vegetation (Biradar *et al*., 2005). Integrated model of time series vegetation index and distinct vegetation classes in geospatial domain is a promising approach for assessment of vegetation condition. Geospatial technique is emerging and serving as a planning tool because of the ability to handle multiple-layers of information in the spatial domain and facilitates the integration and geospatial modelling of these parameters to arrive at inputs for decision-making. Geospatial modelling and integration allows the visualization of information from newer perspectives.

Geospatial modelling tool thus has been used to determine important process of vegetation dynamics and health conditions. The geospatial database has been generated using multi-scale time series satellite remote sensing data. The land use / land cover databases have been integrated to infer landscape processes and patterns. The vegetation dynamics have been studied by assessing the pattern of change and weightage at pixel level for the given set of the forest class. The spatial pattern of Normalized Difference Vegetation Index (NDVI) regimes has been estimated for different forest types over 12 month periods and they have been an input for the habitat health index modeling.

It is necessary to calculate the viability index for each natural vegetation site in order to recommend them for future protection. Only the sites with natural vegetation (i.e. forest, grassland, mangrove, etc.) are considered. Well-known NDVI was used as prime input to measure habitat health or habitat condition within the given sites. The NDVI value has been clustered into a practical number of groups, which are four categories to match with the other existing parameters. This group has been finally clustered into 4 groups (1 to 4); 1 being the worst or highly disturbed and 4 being the best with least disturbance. A suite of the techniques and time series datasets have been used to characterize the habitat conditions.

Multi-spectral, multi-resolution and multi-temporal data: In this study, MODIS 500 m, MODIS 250 m and Landsat Geocover 100 m data sets have been used for the analysis. MODIS 500 m product consists of 36 bands, however only first 7 of the MODIS 500 m and MODIS 250 m with 2 bands were processed. The MOD09 is computed from MODIS level 1C land bands 1–7 (centered at 648 nm, 858 nm, 470 nm, 555 nm, 1240 nm, 1640 nm, and 2130 nm). The product is an estimate of the surface reflectance for each band as it would have been measured at ground level if there was no atmospheric scattering or absorption (Vermonte *et al*., 2002). The original MODIS data are acquired in 12-bit (0 to 4,096 levels), and are stretched to 16-bit (0 to 65,536 levels). Dividing these data by 100 will make them comparable to laboratory spectra in the 0 –100 percent range (Tables 2 & 3).

This single mega-file data provides flexibility to work with the required bands (Thenkabail *et al*., 2005). The data is in at-satellite exo-atmospheric reflectance (0 –100%; there maybe an odd pixel of noise with >100 reflectance – ignore it or write a code to eliminate it).

Preparation of mega datasets: Long time-series analysis of MODIS data requires construction of mega-datasets that involve hundreds of bands. MODIS 500 m data consist of 287 bands (41 images * 7 bands) for year 2003 and 2004 were formulated into a single mega- file of approximately 5 GB. A separate 12 and 24-band NDVI mega file (one NDVI band for each date) was also created. The single mega-file facilitates (a) analysing the time series in their entirety (i.e. they perform unsupervised classification of 287-band data and determine how classes change in magnitude and direction over space and time) and (b) tracking quantitative changes at any level in near-continuous mode (i.e. NDVI variations at pixel or entire study area level in 8-d time interval) (Biradar *et al*., 2003). Monthly maximum value composites (MVC) data have been derived using 8 composites.

MODIS data at 250 –500 m resolution did not yield satisfactory results for smaller vegetation patches even after removing spectacles. To overcome this coarse resolution, Landsat Geocover 2000 at 100 m data was integrated to MODIS mega-file. Combination of time-series data with high resolution data has shown desirable results.

The mega-file facilitates: (a) analysis of the time series data in their entirety (unsupervised classification of 294 bands data), and (b) tracking quantitative changes at any level in near-continuous mode (i.e. NDVI variations at pixel or entire study area level in 8-d time intervals).

Maximum value composites (MVC): Due to cloud cover problem in the study area, monthly maximum value composites of NDVI have been calculated and applied to reduce cloud contaminated pixels in image scenes and eliminate the differences of vegetation spectral responses due to phenological processes captured in the longcompositing period. The MVC rule makes use of the selection of highest NDVI pixel values from the image to make a composite consisting of maximum NDVI of the image area over the chosen period of time.

***Iterative Self-Organizing Data Analysis Technique (ISODATA) clustering (unsupervised classification)*:** In an unsupervised classification, the objective is to group the multi-band file into a number of clusters that are statistically separable. Thus, the range of values in all layers can establish one cluster hereafter referred to as class that is set apart from a specified range combination for another class. Erdas imagine® uses the ISODATA algorithm to perform an unsupervised classification. The ISODATA clustering method uses the minimum spectral distance formula to form clusters. The arbitrary cluster means from the accumulated signature during the initial process have been used for the clustering. The new cluster means are used for the next iteration till it reached to define a maximum of eight iterations with a convergence threshold of 99 percent. Diagonal axis mean statistics with an automatic scaling range standard deviation, with respect to number of classes assigned, was selected for unsupervised classification.

***Signature assessment*:** Generated signature (sig) file during the isodata clustering was used to extract signature means of each class with respect to all bands. Class-wise means of all the band information have been organized in excel worksheet for the assessment of signature behaviour in space and time. This information has been used for the discrimination or grouping of the cluster into four classes.

***NDVI based Viability Index*:** The geospatial database has been generated using multiscale time series satellite remote sensing data. The land use / land cover database have been integrated to infer landscape processes and patterns. The vegetation dynamics has been studied by assessing the pattern of change and weightage at

Table 2: MODIS Terra 500 m 7-band reflectance data characteristics used in this study

MODIS bands No.	MODIS bands Band width nm^3	MODIS Band center nm^3	Potential application
3	459-479	470	Soil/Vegetation Differences
4	545-565	555	Green Vegetation Absolute Land Cover
1	620-670	648	Transformation Vegetation Chlorophyll
2	841-876	858	Cloud Amount Vegetation Land Cover Transformation
5	1230-1250	1240	Leaf/Canopy Differences
6	1628-1652	1640	Snow/Cloud Differences
7	2105-2155	2130	Cloud Properties Land Properties

Table 3: Detailed characteristics of Landsat ETM+ satellite sensor data used to derive Geocover 2000

Sensor	Spatial Resolution (m)	Spectral Resolution (No.)	Radiometric Resolution (bit)	Band Range (nm)	Band Centers (nm)	Band Widths (nm)	Irradiance (W/m^2Sr mm)
Landsat ETM+	30m	7	8-bit	0.45-0.52	0.482	0.65	0.1970
”	”	”	”	0.52-0.60	0.565	0.80	0.1843
”	”	”	”	0.63-0.69	0.660	0.60	0.1555
”	”	”	”	0.50-0.75	0.625	0.15	0.1047
”	”	”	”	0.75-0.90	0.825	0.20	0.2271
”	”	”	”	10.0-12.5	11.450	2.50	--
”	”	”	”	1.55-1.75	0.165	0.26	0.8053

pixel level for the given set of the forest class (Biradar *et al*., 2003). The spatial pattern of NDVI regimes has been estimated for different forest types over 12 month periods and this is an input for the viability (health) index modelling.

Viability Index (VI): *f* (Vegetation cover types, Time series NDVI)

$$VI = \int^{n}_{t=1} (VC_1 * Wt_1 * NDVI_t + VC_2 * Wt_2 * NDVI_t + VC_n * Wt_n * NDVI)$$

where,

VI = Viability Index, VC = Vegetation cover types, Wt = Weightages, NDVI = Normalized Vegetation Index, t = Times series (12 months)

The NDVI can be calculated using the formula;

$$NDVI = \frac{(IR - R)}{(IR + R)}$$

Once the initial classification and signature assessment were completed, the unsupervised gray-scale thematic image was used to identify each class and label them, based on the procedures explained below. Classes were identified and labelled based on the NDVI thresholds. Any change that occurs even at a single pixel is tracked by its location in brightness, greenness and wetness feature space.

Finally, all the classes identified based on the four separable distinct NDVI thresholds has been recorded to its next value of the main segment and so on to facilitate overlaying into a single thematic layer consisting of all the classes extracted at different levels for the particular threshold (Figure 2).

Multiscale and time series NDVI can be applied in conjunction with land use / land cover type for monitoring vegetation health condition and changes across time and space. This technique is especially useful when primary measurements of vegetation and health conditions are lacking in large areas, for example national level assessments.

Geospatial analysis becomes more easy and economic with the increased availability of quality remote sensing data. Especially, MODIS reflectance and NDVI data from 250 m to 500m that measure vegetation cover and condition will be beneficial for satellite data users, particularly in large projects of Sri Lanka.

Determination of viability of status in the context of size, condition and landscape

The continued existence of the organisms in a given ecosystem will depend upon maintaining the natural processes that allowed them to establish and thrive in the past. Embedded in the eco-regional conservation planning is the notion of "viable native species and community types". Viability refers to the ability of a species to persist for many generations or a community/ecological system to persist over some specified time period. Within a planning context, viability may refer to either the viability of a population or the viability of the species as a whole, or similarly to the viability of an entire community or ecological system versus individual examples of it. The viability assessment of conservation sites is an essential pre-requirement to ensure that sites in eco-regional portfolios are as functional as possible and that conservation targets, i.e. communities or species, contained in them have high likelihood of remaining extant (Lamberson *et al*., 1992).

Selection of indices of viability for target areas**:** Ideally viable sites are: (i) essentially not too impacted by man-made alterations to the environment; (ii) at least are well managed and protected by sensitive environmental spatial plans; (iii) large enough to contain viable populations of animals and plants and also to buffer the area from threats and (iv) have a robust shape without long boundaries relative to their surface area. Such ideally viable sites are also connected to other areas and not isolated, so as to allow gene flow from other demes as well as to allow movement to mobile species to obtain living resources from a variety of areas.

In this exercise, viability of target areas was judged on a combination of indices that reflect broad measures of ecological health (habitat health or habitat vigour) and also reflect its viability for biological diversity. For example, an individual large intact rain forest, which has never been cut or disturbed and is in proximity to other rain forest patches, is likely to be in excellent ecological condition. It is also likely to contain a rich assemblage of those species that are endemic to rainforests or that at some time utilize rain forests as habitats. The corollary is that a smaller area of rain forest in similar condition, or a similar large area which has been cut or disturbed, or a more isolated area would both be likely contain fewer species and have a lower biological diversity compared to the aforementioned situation.

Ecological Communities / systems – indices of viability**:** Three primary factors govern the viability of a community or an ecological system: a) demography

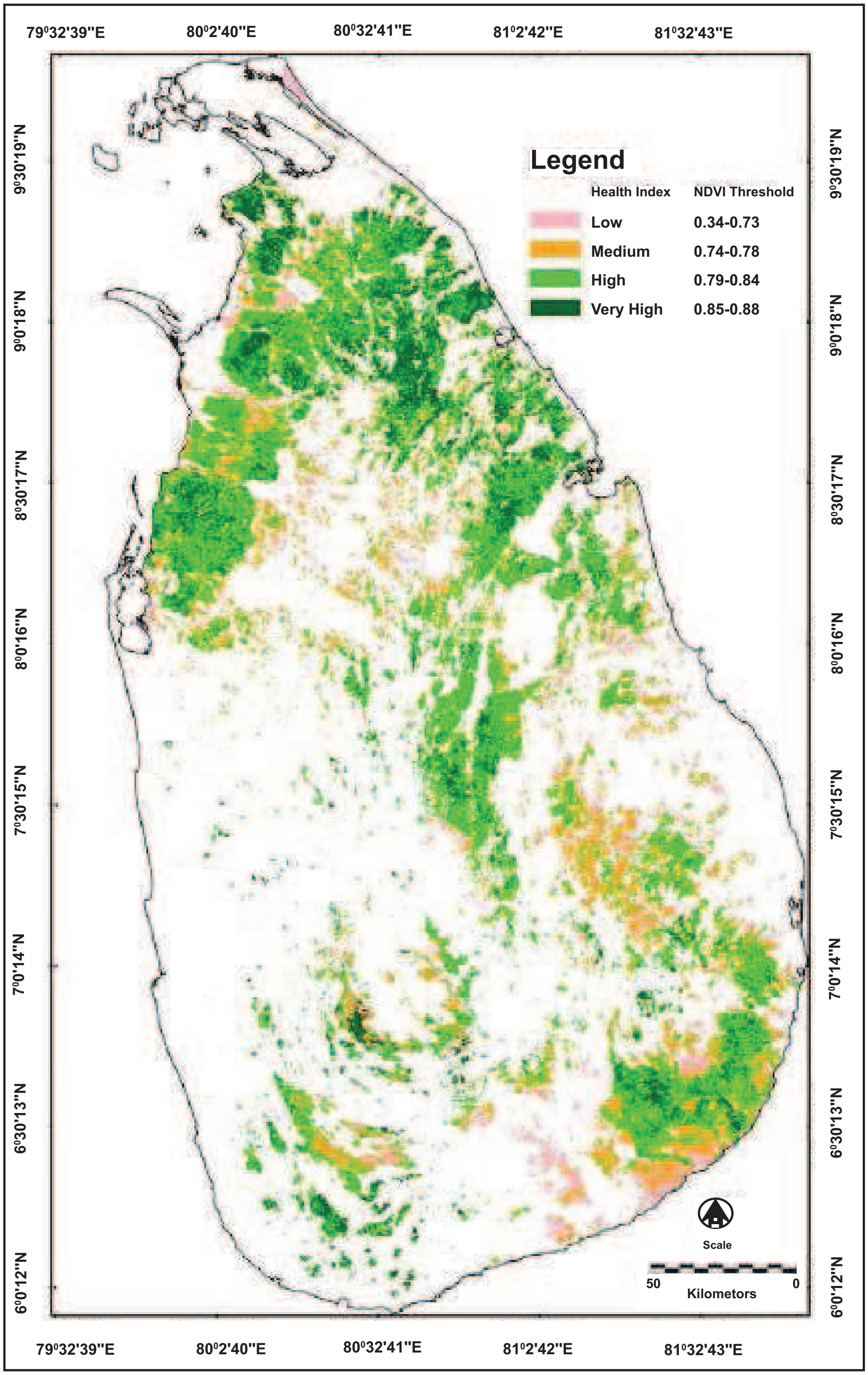


Figure 2: Habitat Health Index map of the Sri Lanka

of component species populations; b) internal processes and structures among these component species and c) landscape-level processes, which sustain the community or system. These factors are roughly equivalent to and certainly incorporated by the criteria of size, condition, and landscape context. One of the most significant challenges in the application of these criteria is factoring in the large-scale change brought about to those communities and systems by anthropogenic disturbance that has occurred in the past (Groves *et al*., 2000).

Based on some important previous exercises (Ranny *et al*., 1981; Hayden *et al*., 1985; Groves *et al*., 2000) the following indices were selected to evaluate the overall viability index for target sites (Figure 3).

Condition Index (= condition inside, habitat health, habitat condition, vegetation index, vegetation health): This is an integrated measure of the quality of biotic and abiotic factors, structures, and processes that characterize targets. Criteria for measuring condition include success and regularity of reproduction, presence/absence of competitors/predators, degree of anthropogenic impacts and presence of biological legacies.

Anthropogenic impacts consist mainly of fragmentation, disturbance to the natural composition (species/ individuals), presence of exotic/invasive species, pollution, etc. Patches that contain relatively continuous cover of natural vegetation (i.e. less fragmentation) are more likely to have intact ecological processes and be free of exotic/invasive species.

Biological legacies accommodate critical features of communities and systems that take generations or sometimes hundreds to thousands of years to develop. For example, in virgin or steady-state or old-growth forests, the presence of fallen logs, composting wood and leaves, a well-developed under-storey and ground flora, and structural complexity in the canopy are examples of such biological legacies. As a general rule, the presence of a well-developed structure and species composition that include characteristic but also uncommon species imply good habitat quality and some historical continuity.

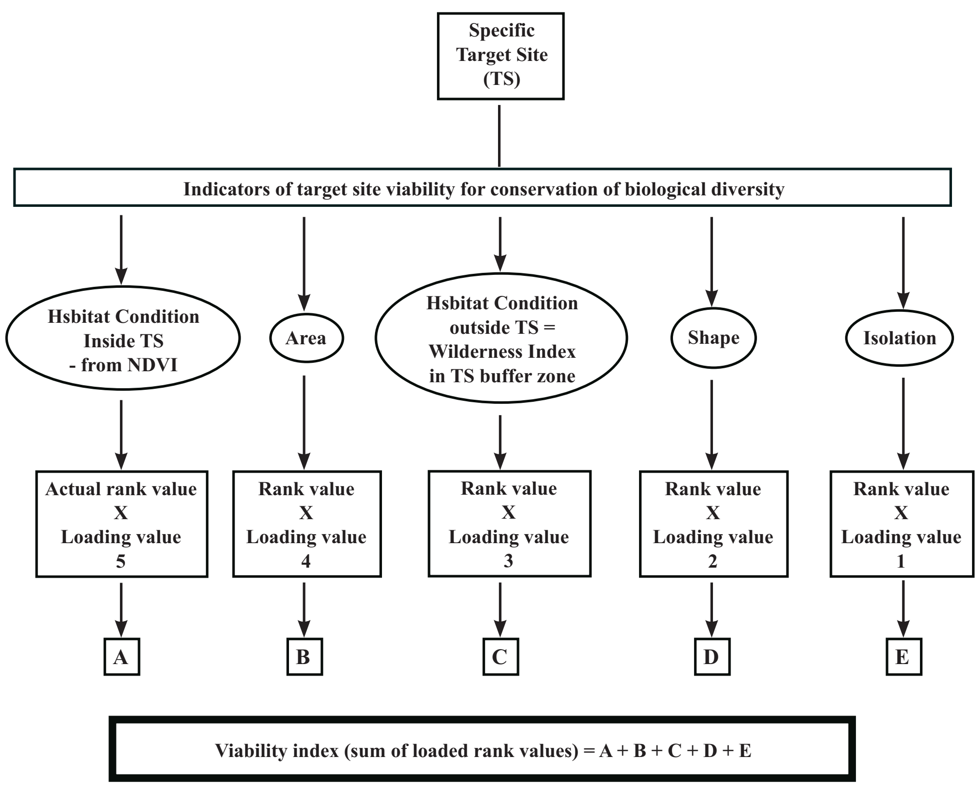


Figure 3: Calculation of Viability Index for a specific target site (TS)

Those communities and systems that are depauperate in species composition for any of a variety of reasons will be ranked as poor sites.

The Condition index or Vegetation index was quantified by spatial patterns of NDVI. It provides a means for obtaining a synoptic view of the status of forest condition on near real time basis. Vegetation type and density maps are the primary spatial layers generated from satellite data. Seasonal data were used to extract the vegetation index depending on forest phenology. The peak growth season, especially in the dry zone where deciduous elements prevail to various extents, is the season following NE monsoon rains that usually end in December. The process is detailed in the previous section.

Area index (= size)**:** At the population level, size is the measure of the area of occupancy by a species and/or its population abundance and density. All else being equal, larger populations are assumed to be more viable than small populations. For matrix-type communities and ecological systems, large-scale natural disturbances create a diverse shifting mosaic of successive stages and physical settings. The area needed to ensure survival or recolonization from such disturbances (i.e. disease, fire, insect outbreaks and landslides) has been called the minimum dynamic area. For a matrix type to persist over time it must be able to sustain, buffer, and absorb these disturbances and maintain these minimum dynamic areas. Size can be determined in two ways for ecological communities and systems. First, the home range of a species (usually a vertebrate) that is a typical occupant of that system and is at the higher end of the food chain can be used to estimate the size of the community or system (i.e. Chesnut-backed owlet in a lowland rainforest). Alternatively there is a rule of thumb from the field of patch dynamics and disturbance ecology which suggests that the size of a community or system needs to be the size of the largest natural disturbance to that community or system over a 500 –1000 year time frame.

Wilderness index (= external condition, outside disturbance index)**:** Categories used in the Wilderness Map prepared by the World Conservation Monitoring Center (WCMC) for Sri Lanka was used to establish disturbance index for the target areas (IUCN & WCMC, 1997). This map used the concept of wilderness (Leslie & Taylor, 1985), which attempts to describe the extent to which nature is changed or disturbed as a result of the influence of modern society on its attributes remoteness and primitiveness. It was developed using the methods which uses the following indicators to derive a wilderness index (Leslie *et al*., 1988):

- Remoteness from settlements (i.e. permanently occupied buildings, cleared agricultural land, plantation forest).
- Remoteness from access (i.e. roads, railways, aircraft runways).
- Aesthetic naturalness, which is the degree to which landscapes are free from the presence of permanent structures of modern technological society (i.e. all man- made structures, ruins and quarries).

Details of the approach used are in the National Conservation Review (IUCN & WCMC, 1997). The Wilderness Index provides a measure of socio-economic influences and threats to closed canopy natural forests and an indicator of the aesthetic naturalness of such sites. It can also serve as an excellent proxy for the condition of the peripheral habitat in the landscape of the target areas. Four wilderness zones are defined approximately as shown in Table 4.

Shape index**:** The interaction of patch shape and size can influence a number of important ecological processes. Patch shape has been shown to influence inter-patch processes such as small mammal migration (Buechner, 1989) and woody plant colonization (Hardt & Forman, 1989), and may influence animal foraging strategies (Forman & Godron, 1986). However, the primary significance of shape in determining the nature of patches in a landscape seems to be related to the "edge effect".

Edge metrics usually are best considered as representing landscape configuration, even though they are not spatially explicit at all. Total amount of edge in a landscape is important to many ecological phenomena. In landscape ecological investigations much of the presumed importance of spatial pattern is related to edge effects. The forest edge effect, for example, results primarily from differences in wind and light intensity and quality reaching a forest patch that alter microclimate and disturbance rates (Gratkowski, 1956; Ranny *et al*., 1981; Chen & Franklin, 1990). These changes, in combination with changes in seed dispersal and herbivory, can influence vegetation composition and structure (Ranny *et al*., 1981). The proportion of a forest patch that is affected in this manner is dependent, therefore, upon patch shape and orientation, and by adjacent land cover. Irregular shaped areas are difficult to manage, have important core areas that are close to boundaries and readily suffer from outside threats. Also, a long and narrow forest patch is more susceptible to outside threats such as encroachment, than a similar sized area that is more robust and circular in shape that better protects the core of the rain forest.

Table 4: The Wilderness index

Category	Wilderness zones	Wilderness index
1	Low wilderness	<5
2	Medium - low wilderness	5-9
3	Medium - high wilderness	9-13
4	High wilderness	13-20

Table 5: Loading multipliers for viability criteria

Viability criterion	Loading multiplier for ranks I, II, III, & IV
Condition Index	5
Area Index	4
Wilderness Index	3
Shape Index	2
Isolation Index	1

A large but convoluted patch, for example, could be entirely edge habitat. It is now widely accepted that edge effects must be viewed from an organism-centered perspective because edge effects influence organisms differently; some species have an affinity for edges, some are unaffected, and others are adversely affected.

Early wildlife management efforts were focused on maximizing edge habitat because it was believed that most species favoured habitat conditions created by edges and that the juxtaposition of different habitats would increase species diversity (Leopold, 1933). Indeed this concept of edge as a positive influence has guided land management practices until recently. Recent studies, however, have suggested that changes in vegetation, invertebrate populations, predation, brood parasitism, and competition along forest edges has resulted in the population declines of several vertebrate species dependent upon forest interior conditions (Strelke & Dickson, 1980; Kroodsma, 1982; Brittingham & Temple, 1983; Wilcove, 1985; Temple, 1986; Noss, 1988; Yahner & Schott, 1988; Robbins *et al*., 1989). Forest interior species, therefore, may be sensitive to patch shape because for a given patch size, the more complex the shape, the larger the edge-to-interior ratio. Most of the adverse effects of forest fragmentation on organisms seem to be directly or indirectly related to edge effects. Total class edge in a landscape, therefore, often is the most critical piece of information in the study of fragmentation, and many of the class indices directly or indirectly reflect the amount of class edge. Similarly, the total amount of edge in a landscape is directly related to the degree of spatial heterogeneity in that landscape.

At the patch level, edge is a function of patch perimeter. The edge effect on a patch can be indexed using the perimeter-to-area ratio employed in the shape index.

***Isolation index (= isolation or nearest-neighbour distance)*:** This is defined as the distance from a patch to the nearest neighbouring patch of the same type of vegetation, based on edge-to-edge distance. Isolation quantifies landscape configuration and can influence a number of important ecological processes. For example, studies on population dynamics and species interactions in spatially subdivided populations suggest that the dynamics of local plant and animal populations in a patch are influenced by their proximity to other subpopulations of the same or competing species. Several authors (Hayden *et al*., 1985; Dickman, 1987) have claimed, for example, that patch isolation explains why fragmented habitats often contain fewer bird species than contiguous habitats. A number of studies that empirically demonstrated an isolation effect on bird communities in various habitat patches have been reviewed (Opdam, 1991). Inter-patch distance plays a critical role in island biogeographic theory (Mac Arthur & Wilson, 1967) and metapopulation theory (Levins, 1970; Gilpin & Hanski, 1991) and has been discussed in the context of conservation biology (Burkey, 1989). The role of inter-patch distance in meta-populations has had a pre-eminent role in recent conservation efforts for endangered species (Lamberson *et.al*., 1992; McKelvy *et al.*, 1992). Clearly the isolation or nearest-neighbour distance can be an important characteristic of the landscape depending on the phenomenon under investigation.

***Loading factors and calculations of viability indices*:** The above selected indices potentially have very different scales of impact on biological diversity within a specific target area. For example, the condition of the habitat within a patch of mangrove is more likely to influence the viability of that patch than, say, the distance from its like neighbour patches. Conversely, if the habitat of a mangrove patch is poor, its diversity will likely be low even if there is a good patch of mangrove habitat close to it. Therefore it is necessary to unify these differential indices by processing them through a loading mechanism (Table 5 and Figure 3) proposed by the Gap Analysis process [7].

The range within each of the five factors is sequenced into four groups or quarters, i.e. very good, good, moderate and poor. The overall ranking of conservation targets (natural vegetation types) is the summation of the five indices for all individual sites within each vegetation type, i.e. mangrove forest. Figure 3 illustrates the steps leading to the gross estimation of the Viability Indices.

***Ranking of focal conservation targets for viability*:** The viability of a focal conservation site is the function of the condition, size, wilderness, shape and isolation factors. The next step will be the ranking of these factors for each focal target based upon the best available knowledge and judgment. Each of the five factors should be ranked as "very good", "good", "fair", or "poor" (Lamberson *et al*., 1992). The rationale for the viability ranks is as follows:

Very Good. Viability reflects at least two "very good" and no "fair" or "poor" ranks for the viability factors.

Good. Various combinations of "very good" to "poor" factors can result in "good" viability. In general, "good" viability reflects at least two "good", or one "very good", and no "Poor" ranks among the viability factors.

Fair. Like "good" viability, various combinations of "very good" to "poor" viability factors can result in "fair" viability. However, in general, "fair" viability reflects at least two "fair", or one "poor", and no "very good" ranks.

Poor. Generally, "Poor" viability reflects at least two "poor" and no "good" or "very good" ranks for the viability factors.

RESULTS

The viability index of 29 biosphere reserves in Sri Lanka was mapped as shown in Figure 4. To demonstrate the

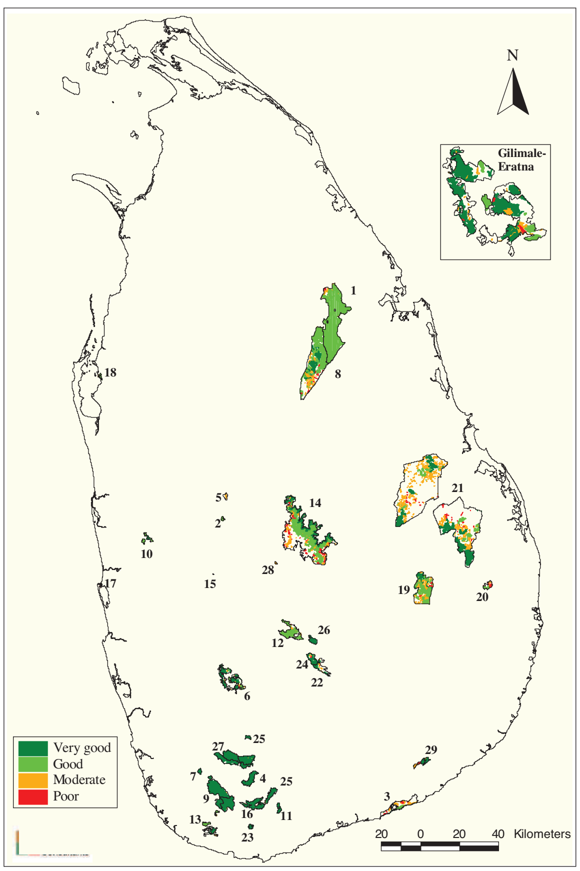


Figure 4: Viability status of the Biosphere Reserves in Sri Lanka
Source: EML Consultants Pvt. Ltd., Colombo.

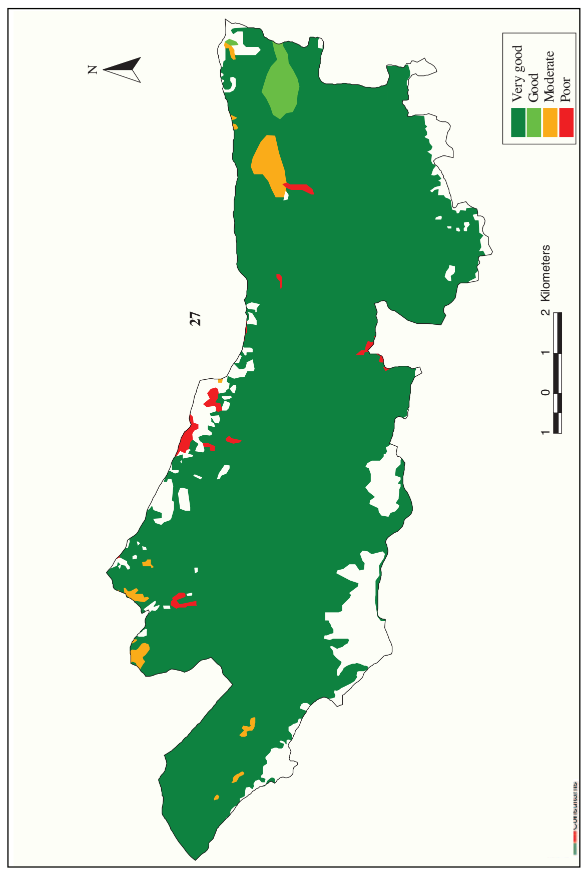


Figure 5: Viability status of the Sinharaja International Biosphere Reserve
Source: EML Consultants Pvt. Ltd., Colombo.

appearance of four viability categories over vegetation patches more clearly, results were depicted in detail for four selected individual Biosphere Reserve sites, *viz*. Sinharaja, the Knuckles, Nuwaragala and Munnakkara (Figures 5, 6 and 7). The vegetation patches (polygons) within each biosphere reserve were divisible into four viability categories, *viz*. very good, good, moderate and poor. In addition, most biosphere reserves included 'blank' areas where no forest patches (polygons) are shown to exist and for them the viability status is indeterminable. This is due to the fact that these 'blank' areas were not represented as vegetation or forest patches in the original forest cover map that was used as the base map in the gap analysis. These 'blank' areas possibly consist of non-forest vegetation such as scrub, grasslands, sand dunes, salt marsh and water bodies.

The corresponding areas and proportions of each of the four viability categories for each biosphere site were also calculated (Table 6). The total area of the biosphere reserves shown in Figure 8 consists of 263,648 hectares that are contained in patches (polygons) of vegetation. Accordingly, of the total biosphere areas, 51,088 hectares (19.3%) are very good, 58,545 hectares (22.2 %) are good, 15,734 hectares (5.9%) are moderate and 3,378 hectares (1.2%) are poor in their viability status. Meanwhile, the viability status of a total area of 134,928 hectares (51.1%) remained indeterminable. It is clearly evident that most of the relatively large biosphere reserves (> 2000 hectares) contain large proportions (> 80%) of highly viable areas (very good and good), i.e. Sinharaja, Anaolundewa, Diyadawa, Kanneliya and Rammalakanda. Of the relatively small biosphere reserves (300 – 500 hectares), Haycock and Oliyagankele stand are prominently viable (> 88% of very good and good viability areas). Small biosphere reserves, such as Munnakkara (Figure 7) and Udawattakele demonstrate complete lack of very good and good viability areas and consist of only areas with moderate and poor viability. These sites are located in highly urbanized areas and are heavily impacted with

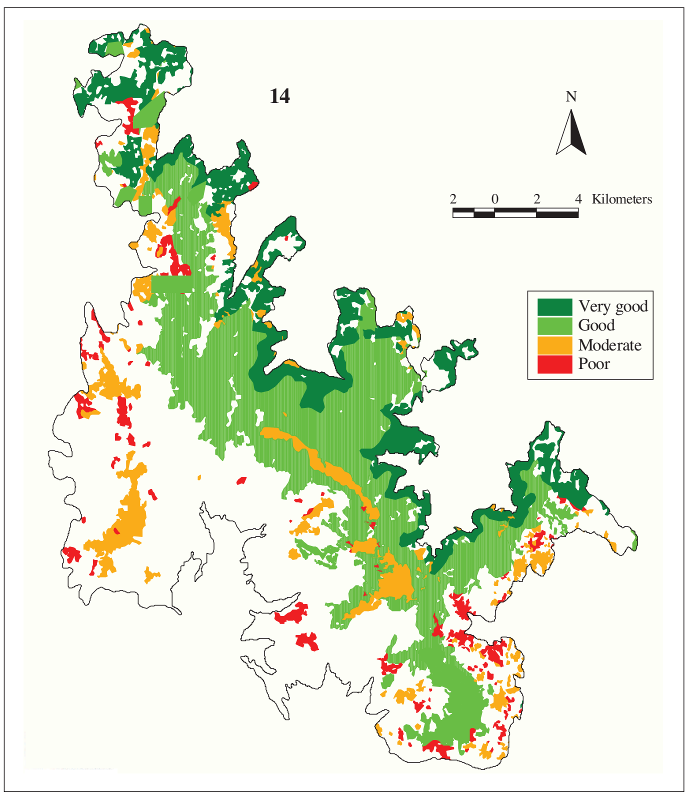
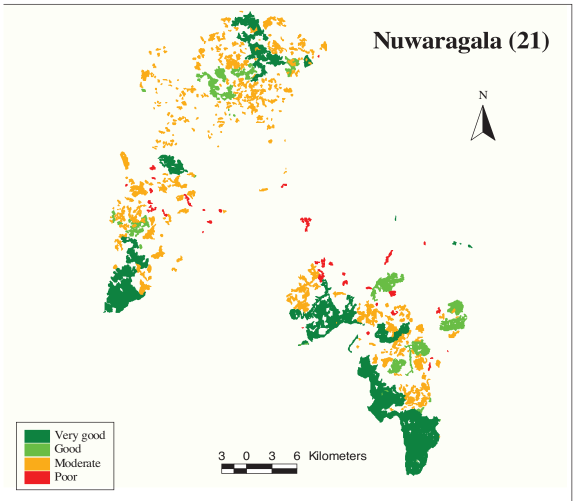


Figure 6: Viability status of the Proposed Knuckles International Biosphere Reserve
Source: EML Consultants Pvt. Ltd., Colombo.

Table 6: Viability status of the biosphere reserves in Sri Lanka

No.	Biosphere reserve	Total area (ha)	VIABILITY STATUS Very good Area(ha)	Very good %	Good Area(ha)	Good %	Moderate Area(ha)	Moderate %	Poor Area(ha)	Poor %	Indeterminable Area(ha)	Indeterminable %
1	Anaolundewa	29422.57	3.33	0.01	25646.29	87.17	579.03	1.97	150.15	0.51	3043.77	10.35
2	Badagamuwa	240.97	0.00	0.00	0.00	0.00	207.89	86.27	0.00	0.00	33.08	13.73
3	Bundala	5043.77	133.84	2.65	395.07	7.83	636.92	12.63	245.02	4.86	3632.93	72.03
4	Diyadawa	2504.87	2180.72	87.06	0.00	0.00	0.00	0.00	20.25	0.81	303.90	12.13
5	Doluwakanda	499.15	0.00	0.00	0.00	0.00	164.24	32.90	0.00	0.00	334.91	67.10
6	Gilimale-Eratne	6237.74	2382.32	38.19	445.41	7.14	402.74	6.46	81.37	1.30	2925.90	46.91
7	Haycock	380.78	338.91	89.00	0.00	0.00	6.59	1.73	0.00	0.00	35.28	9.27
8	Hurulu	25497.58	3248.39	12.74	8845.44	34.69	1734.19	6.80	426.05	1.67	11243.50	44.10
9	Kanneliya	11514.11	9601.48	83.39	112.77	0.98	139.24	1.21	148.29	1.29	1512.37	13.13
10	Kankaniyamulla	878.66	214.19	24.38	468.78	53.35	0.00	0.00	0.00	0.00	195.69	22.27
11	Kanumuldeniya	674.23	519.20	77.01	0.00	0.00	13.33	1.98	0.00	0.00	141.70	21.02
12	Kikilimana	4879.19	0.00	0.00	3097.28	63.48	185.11	3.79	150.39	3.08	1446.41	29.64
13	Kombala-Kottawa	2108.56	434.36	20.60	405.00	19.21	76.52	3.63	4.93	0.23	1187.74	56.33
14	Knuckles	38938.64	4725.61	12.14	11179.28	28.71	2840.01	7.29	1129.31	2.90	19064.43	48.96
15	Kurulukele	9.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.02	100.00
16	Mulatiyana	3603.53	2675.16	74.24	0.00	0.00	187.61	5.21	33.46	0.93	707.30	19.63
17	Munnakkara	51.01	0.00	0.00	0.00	0.00	28.56	55.98	22.45	44.02	0.00	0.00
18	Nagamadu	245.59	0.00	0.00	227.07	92.46	18.52	7.54	0.00	0.00	0.00	0.00
19	Nilgala	12008.15	1619.14	13.48	4593.57	38.25	1364.23	11.36	119.53	1.00	4311.68	35.91
20	Nellikele	1238.17	0.00	0.00	197.61	15.96	58.70	4.74	157.70	12.74	824.15	66.56
21	Nuwaragala	98607.08	9606.24	9.74	2687.97	2.73	6349.46	6.44	510.24	0.52	79453.00	80.58
22	Ohiya	2466.41	561.72	22.77	32.15	1.30	127.72	5.18	4.15	0.17	1740.68	70.58
23	Oliyagankele	436.97	386.33	88.41	0.00	0.00	14.63	3.35	0.00	0.00	36.01	8.24
24	Pattipola-Ambawela	1954.50	916.77	46.91	83.06	4.25	65.99	3.38	25.50	1.30	863.18	44.16
25	Rammalakanda	2110.09	1694.75	80.32	0.00	0.00	71.93	3.41	4.38	0.21	339.03	16.07
26	Sita Eliya	1067.09	711.55	66.68	0.00	0.00	0.00	0.00	1.53	0.14	354.01	33.18
27	Sinharaja	9572.68	8308.67	86.80	114.13	1.19	144.71	1.51	81.71	0.85	923.45	9.65
28	Udawattakele	118.72	0.00	0.00	0.00	0.00	64.50	54.33	0.00	0.00	54.22	45.67
29	Wedasitikanda	1365.81	825.35	60.43	15.09	1.10	251.78	18.43	62.34	4.56	211.25	15.47
	Total	**263675.60**	**51088.03**	**19.38**	**58545.94**	**22.20**	**15734.15**	**5.97**	**3378.73**	**1.28**	**134928.61**	**51.17**



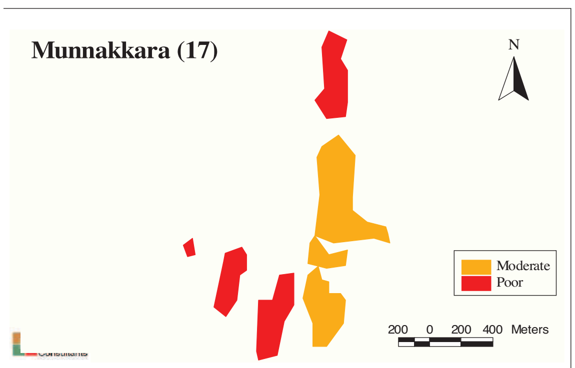


Figure 7: Viability status of Nuwaragala and Munnakara National Biosphere Reserves
Source: EML Consultants Pvt. Ltd., Colombo.

human activities. Kurulukele is the smallest biosphere reserve in Sri Lanka consisting of only 9.02 hectares. It is also surrounded by heavily urbanized areas. Not having been mapped as a forest patch, its viability index remains indeterminable. Meanwhile, some relatively large (> 2000 hectares) biosphere reserves contain large proportions of non-forested areas for which the viability status is indeterminable, i.e. Nuwaragala (80.5%), Bundala (72%), Ohiya (70.5%) and the Knuckles (48.9%).

DISCUSSION

As the bulk of the terrestrial biodiversity is contained within natural vegetation, the latter is considered as the best proxy to represent many other conservation targets, such as ecological systems and species. The evaluation of the viability of the biosphere reserves in Sri Lanka is an important technique that ensures the long-term stability of the component ecosystems within these reserves. One of the most important determinants of viability is the assessment of the threats that are connected to the impact of socio-economic factors. The viability indices directly reflect stress enforced on nature mainly by anthropogenic activities. Therefore, the information on the viability will be an important tool in the management of natural resources. However, it is recommended that the results should be ground-truthed in order to check their accuracy. Biosphere reserves often consist of a mixture of natural and managed landscapes, thus forming mosaics of ecological systems. As the MAB concept is founded on the principle of conservation and sustainable use of natural resources by the communities, zoning of the Biosphere Reserves into core area(s), buffer zone(s) and transition zone(s) is a strategy to manage such mosaics while promoting the above principle. Zoning can be greatly assisted by the use of viability index. Highly viable areas are generally selected for strict conservation while moderately viable areas can be allocated for sustainable use. Poorly viable areas are recommended to be restored. The areas that are mapped as 'blank' areas should be ground-truthed for the existence of non-forest vegetation and appropriate measures be employed to conserve special vegetation types or habitats or restore degraded habitats. It is expected that the forest and wildlife managers will use this new technique in the management of the biosphere reserves as well as other protected areas.

Acknowledgement

Inducement from Mr. Avanthi Jayatilleke, CEO and the technical support provided by Mr. Asoka De Alwis, GIS Technologist of the EML Consultants (Pvt.) Ltd., were important in preparing this paper. The technical facilities and materials provided by the International Water Management Institute (IWMI) were crucial for determination of habitat health of the biosphere reserves. The National Science Foundation, Colombo accommodated the presentation of this paper at the International Conference on Humid Tropical Ecosystems. Our sincere thanks are due to these institutions and personnel.

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