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The map of potential vegetation of Nepal

a forestry/agro-ecological/biodiversity classification system

Barnekow Lillesø, Jens-Peter; Shrestha, Tirtha B.; Dhakal, Lokendra P.; Nayaju, Ratna P.; Shrestha, Rabin

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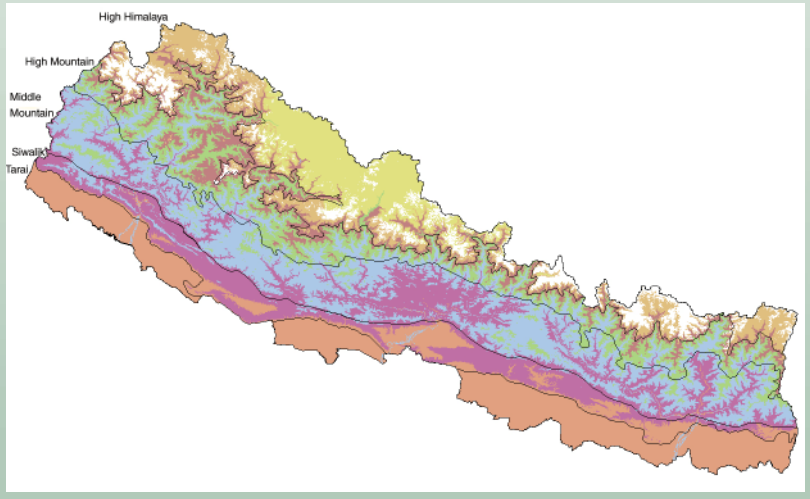

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Preface

The natural vegetation of Nepal provides a very important basis for sustaining the livelihoods of people in Nepal's rural society, which accounts for over 90% of the nation. The description of the variation in the different landscapes that varies from tropical forests and grasslands to alpine meadows and deserts has long been a challenging task.

The Tree Improvement and Silviculture Component (TISC) of the HMG/Danida Natural Resources Management Sector Assistance Programme (NARMSAP) recently published 'Forest and Vegetation Types of Nepal' (Shrestha *et al*., 2002). The document and GIS map and database is an important synthesis of the ecological zonation and distribution of vegetation types and plant species in Nepal.

In the present document the background for and implementation of the work to complete the map and database is explained. In the spirit of J. F. Dobremez - who was the driving force in the production of the hard copy vegetation maps made in the 1970's and 1980's - the present authors suggest that the ecological zones and vegetation types should be conceived as the containers of different ecosystems - natural, semi-natural and man-made - and the natural vegetation should be conceived as only one of the possible contents in that container.

The document therefore describes the various attempts at establishing recommendation domains for agricultural production to the benefit of Nepal's rural population and how the new GIS map and database can be utilised by many different sectors in natural resources management.

In addition to the description of the variation in vegetation, the authors introduce a new climate classification in Nepal based on 261 meteorological stations in the country and extensive analysis by an expert from the Department of Hydrology and Meteorology (the co-author of the present paper). The classification is based on more stations than any previously published account. The classification presents the climate in the context of the Potential Vegetation Map.

We hope that the present document will inspire institutions and organisations in Nepal to discuss what constitutes a good framework for understanding the tremendous variation of climate, vegetation, farming systems, and biodiversity in Nepal.

The Map of Potential Vegetation of Nepal - a forestry/agro-ecological/biodiversity classification system has been developed as a joint effort between TISC and Danida Forest Seed Centre (now *Forest & Landscape Denmark*) within the overall framework of the collaborative natural resource management programme between HMG/Nepal and Danida.

Lars Graudal
Head of Department

Summary

The intention of this paper is to introduce the Potential Vegetation Map as a potential tool in Nepal in the fields of Forestry, Agriculture, Horticulture, Livestock, and Biodiversity/Conservation.

The introduction in chapter 1 explains that the purpose of this paper is to inspire people working with natural resource management in Nepal to discuss what constitutes a good framework for understanding the tremendous variation of climate, vegetation, farming systems, and biodiversity in Nepal.

Chapter 2 explains how the Potential Vegetation Map is based on work carried out in Nepal over a period of more than 30 years by a large number of people and organisations, and how the method of vegetation mapping relates to other vegetation classification carried out in the rest of the world. The chapter also gives a brief account of the work of the main authors at the different stages of development of the map.

Chapter 3 introduces a new climate classification in Nepal based on 261 meteorological stations in the country and extensive analysis by an expert from the Department of Hydrology and Meteorology (the co-author of the present paper). The classification is based on more stations than any previously published account. The classification presents the climate in the context of the Potential Vegetation Map.

Chapter 4 presents the physiographic classification of Nepal. This is a classification used by practically all Government Departments, Donors, Non Government Organisations and field workers in Nepal. It divides Nepal into 3 to 5 'horizontal sections'.

Chapter 5 presents some of the important requirements of an agro-ecological classification and also shows that the physiographic classification only partly fulfils the requirements of an agro-ecological classification.

Chapter 6 presents a brief account of agroecological classification in Nepal and how the Potential Vegetation Map relates to these other classifications.

Chapter 7 looks at the major objectives of the Forest Sector Policy (2000), the Agricultural Perspective Plan (1995), and the Nepal Biodiversity Action Plan (2000) and briefly outlines how these programmes would benefit from utilising the potential of the Potential Vegetation Map.

Chapter 8 discusses how the power of the Potential Vegetation Map can be increased by utilising the map and by incorporating more information into the system by establishment of a cross-sectoral Board to spearhead the continuous updating.

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Acronyms

BPP	Biodiversity Profiles Project
DFRS	Department of Forest Research and Survey, Ministry of Forests and Soil Conservation, Kathmandu, Nepal
ICIMOD	International Centre for Integrated Mountain Development
IUCN	The World Conservation Union
MENRIS	Mountain Environment and natural Resources Information Systems
PA	Protected areas
TISC	Tree Improvement and Silviculture Component, Ministry of Forests and Soil Conservation, Kathmandu, Nepal

1 Introduction

The purpose of this paper is to introduce the potential of the Potential Vegetation Map as a tool for management of natural resources in Nepal. The paper is not intended as an extension tool[1], but rather to provide inspiration for people working with natural resource management in Nepal to discuss what constitutes a good framework for understanding the tremendous variation of climate, vegetation, farming systems, and biodiversity in Nepal.

Few if any other countries in the world contain such a range of climates over such short distances as Nepal. In a matter of few kilometres - as the crow flies - the crow will move from 'Honduras' to 'Alaska' or from 'Thailand' to 'Mongolia'.

Until a few years ago it was not practically possible to map the enormous diversity of Nepal in detail and a very broad classification is still used by nearly everyone in Nepal. With the advent of inexpensive computing power and user friendly software it should no longer be necessary to lump together 'Alaska' and 'Thailand' when providing extension advise to forest user groups, farmers, and conservationists.

In a separate document the content of the GIS system of the Potential Vegetation map has been documented. The Ecological Zones and Potential Vegetation types in Ecological Zones are described and the potential species of trees, shrubs, herbs, and grasses are detailed in Shrestha *et al*. (2002).

J. F. Dobremez (main author of the hard copy maps made in the 1970's and 1980's) expressed that the zones and vegetation types should be conceived as the containers of different ecosystems - natural, semi-natural and man-made - and the natural vegetation should be conceived as one of the possible contents in that container.

TISC plans to find out – in collaboration with experts in the various fields (across the many sectors) of natural resource management - how the containers can be filled in the best possible way to the benefit of the millions of people making a life in the different Ecological Zones and Potential Vegetation Types of Nepal.

The present report is therefore also a suggestion for collaboration between the different organisations concerned with land use in Nepal.

[1] The Potential Vegetation Map can, however, be used to produce extension tools

2 Elaboration of the Potential Vegetation Map

The Map of Potential Vegetation of Nepal and the species database has in the present version been underway for three years. The content of the map is, however, the synthesis of vegetation studies carried out over the past 30 years in Nepal and it has been matched to work carried out in forestry, agronomy, horticulture, biodiversity and several other fields.

The elaboration of the map was made possible by the combined work of practitioners within natural resource management in Nepal and by the recent advent of inexpensive computing power and user-friendly software.

The Map of Potential Vegetation of Nepal should be considered a representation of the natural resources of Nepal as described by the potential vegetation types. The vegetation type is an expression of climate and soils, and indicates the potential both in terms of potential availability of natural vegetation and wildlife and in terms of agro-ecological potential.

The intended use of the map is to have a unified interpretation of the landscape in Nepal that can be utilised for planning natural resources both wild, tended and planted.

The documentation of the database and of the map and description of the Ecological Zones and vegetation types are presented in Shrestha *et al.* (2002). The documentation of the climate data is presented in Nayaju & Lillesø (2000).

2.1 A brief account of vegetation classification and the history of making the Potential Vegetation Map

Phytosociologists[2] classify plant communities through a process of interaction between the environment and vegetation. The phytosociologist moves through the landscape and observes that certain kinds of communities repeat themselves: similar combinations of species appear under certain environmental conditions. Similar communities, once observed, are grouped together into vegetation types (Whittaker, 1978). The phytosociologist may describe the classes in terms of structure, floristic composition or dominance of species.

It has been discussed widely if identified vegetation types are artificial or natural units, because (i) species are distributed 'individualistically' each according to its own way of relating to the environment, hence not two species are alike. Because individualistic species are combined with one another in varied combinations and proportions in plant communities, the phytosociologist must choose what combinations he/she is to recognise as associations or other community types; (ii) plant communities often (usually, if not affected by different disturbances or by environmental discontinuity) intergrade continuously and boundaries are in consequence often arbitrary (Whittaker, 1978).

[2] Phytosociologist: scientist that classifies vegetation

The implications of the individualistic distributions of species and the intergraded boundaries of plant communities are that (i) there are many possible approaches to classifying communities, emphasising different kinds of characteristics as bases of classification; (ii) no one approach to classification can claim exclusive merit; (iii) there may be merit in an open-minded and informal classification, seeking for each vegetation area and research purpose a most useful classification; (iv) there is value in a standardisation of the approach to classification. Such standardisation favours the efficient collection, organisation, and communication of information about plant communities and makes possible the effective relation of research of each individual to that of many others (Whittaker, 1978).

A large number of schools have developed different systems of classification adapted to different kinds of landscapes and research interests. The earliest means of classification in the early eighteenth century was by vegetation structure or physiognomy. Over time different schools developed in Southern and in Northern Europe, in Russia, Britain and North America. Three schools are of special relevance to the elaboration of the Potential Vegetation Map.

In the North American understanding (lead by Clements) vegetation communities developed by succession towards a single climatic climax adapted to a geographic region and characterised by a static species composition of the vegetation (described by what was considered dominant species). Even in North America this was early on dissented by other North American researchers (most notably Gleason) who asserted the principles of species individuality and vegetational continuity (Whittaker, 1978), the basic belief of Clements that all succession leads to a stable final climax stage (or super-organism), however, was taken over by Eugene Odum who advocated that all ecosystems will eventually become stable mature ecosystems in equilibrium (Worster, 1994). The paradigm that ecosystems are in equilibrium with static species compositions of dominant species has been challenged in recent years, for a wide range of ecosystem types, and it is doubtful that any vegetation type can be considered stable (Pickett & Cadenasso, 1995).

The British tradition used the vegetation formation as a unit but interpreted it in terms of successional processes, where several types of 'climaxes' were possible in a climatic region, not simply as a regional climax unit. Formations were divided into broadly defined 'associations' characterised by their dominant species (Whittaker, 1978).

The South European tradition (most notably the Zurich-Montpellier school lead by Braun-Blanquet) has been characterised by concern with full floristic composition of vegetation, and by the creation for community taxonomy of a formal hierarchy of which the association is the basic unit. Vegetation samples (relevés) are grouped into community types by similarity of composition, especially representation of character species (character species are species whose distributions are centred in, or largely limited to, a given community type). The basic unit of the system is the association; associations are grouped into higher units termed alliances, alliances into orders, and orders into classes to produce a formal hierarchy of community classification (Whittaker, 1978).

Both the British and the South European schools have divided vegetation gradients into zones in mountains in Europe and in the tropics combining a classification of vegetation types with ordination (relating these units to one another along environmental axes) (Whittaker, 1978).

The system of Braun-Blanquet is the most widely applied and most effectively standardised of all approaches to classification, and has been adapted to diverse kinds of communities (Whittaker, 1978), although it has shown difficult to apply a meaningful hierarchy of vegetation types to very species rich forest (Hall & Swaine, 1981; Gauch & Whittaker 1981).

In recent years a new paradigm has emerged, which is relevant to the way vegetation types are classified and described. The new paradigm predicts that species communities may to a large extent be random assemblages of species. How common species are and how they are put together in communities (associations) may be random to a large extent (and not completely determined by ecological niches of species as assumed in the climax theory of Clements), although which families, how many species, and possibly what individual species make up a plant community may nevertheless be deterministic and predictable from simple environmental parameters (Gentry, 1988; Ashton, 1996; Terborgh *et al.*, 1996; Hubbell, 1998).

2.2 A brief account of the landscape and vegetation classification in Nepal

The concept of landscapes can be considered in two ways (Pickett and Cadenasso, 1995). The first, which considers a landscape as a specific area based on human scales is intuitive: Landscapes are ecological systems that exist at the scale of kilometres and comprise recognisable elements, such as farm fields, human settlements, and natural ecosystems. The second use of landscape is an abstraction representing spatial heterogeneity at any scale. The basic question about scale consists of determining whether a given phenomenon appears or applies across a broad range of scales, or whether it is limited to a narrow range of scales (Wiens, 1989; Pickett and Cadenasso, 1995).

The Potential Vegetation Map attempts to show the broad patterns in the landscapes of Nepal as determined by altitude and biogeography (east-west patterns). At this scale it is possible to predict the potential distribution of species or potential for agricultural crops. At a smaller scale than is presently shown by the Potential Vegetation Map new patterns will emerge e.g. *Lagerstromia parvifolia* and *Pinus roxburghii* occur at the same altitudes, but *Lagerstromia parvifolia* will mainly occur on north facing slopes, while *Pinus roxburghii* will mainly occur on south facing slopes. At a certain altitude suitable for growth of Citrus, farmers (from experience) will plant it on south facing slopes to avoid frost that may occur on north facing slopes.

In many parts of Nepal, especially in the tropical and subtropical zones, the remnant vegetation occurs in fragments of their former extent (see also map 7 for an example from the Lower Tropical Zone). Although all landscapes can

be thought of as a mosaic, a human dominated landscape is composed of discrete patches of remnants of natural vegetation and farm fields (Christensen, 1989). In Nepal, the overriding factor of relief changes the content of the patches both of farm fields and of natural vegetation.

The interpretation of the Nepalese landscape is therefore heavily influenced by human activity. Forests consist of long-lived trees and their species composition therefore reflects events that happened a hundred years ago. Any classification of vegetation types will to an unknown extent be influenced by human impact as well as environmental.

Habitat fragmentation is a major cause of biodiversity erosion in many forests and often predictable shifts in species composition occur as forest fragments are reduced in size, certain types of plant species may become rare or disappear, e.g. species dependent on birds and other animals for dispersal of seeds and shade tolerant species (Tabarelli *et al*., 1999; Murcia, 1998) and species especially useful for humans, e.g. fodder trees (Lillesø *et al*., 2001a; Lillesø *et al*., 2001b, Dhakal *et al*., 2001). The effect of fragmentation on the elements of the flora and fauna has not been studied in great detail in Nepal, however, experience elsewhere indicates that comprehensive planning at the level of whole landscapes and regions is necessary to mitigate the effects of fragmentation (Terborgh, 1992; Simberloff. 1998; Simberloff, 1999, Soulé & Terborgh, 1999).

2.2.1 The approach of Stainton and Dobremez and Shrestha

2.2.1.1 Stainton and co-workers

J. D. A. Stainton's (Stainton, 1972) forest type classification has probably been more used in Nepal than Dobremez' classification, although the two classifications are very compatible and only Dobremez provided maps (the main reason for this is probably that the Dobremez work was never translated from French into English!)

Although Stainton in his book does not refer to any phytosociological theory (in the sense described above) his methodology is clearly phytosociological:
'I would guess what the predominant vegetation was likely to be as I crossed to a slope with a different aspect or climbed to a slope above; or on entering a certain type of forest I would guess at which old friends among the trees I knew by name I was likely to find within it….. My next step was to make notes on the composition of the various types of vegetation, until on my later trips, and fortified by now with knowledge of the standard ecological works published on the Himalayan flora, the making of these notes became my primary objective' (Stainton, 1972 p. 3)

2.2.1.2 Dobremez and co-workers

The school of vegetation classification developed at Grenoble, France (a variant of the Zurich-Montpellier School, see above) was used to study the phytogeography of the southern alps (Ozenda 1966). It was applied for Nepal by J. F. Dobremez (1976) in collaboration with a number of French scientists and Nepalese botanists from HMG Department of Medicinal Plants (now renamed

as Department of Plant Resources), under the Ministry of Forests and Soil Conservation during 1970-1985. The work resulted in a series of ecological maps (Shrestha *et al*., 2002).

The information for vegetation analysis and subsequent synthesis to define homologous areas was assembled through five successive steps as follows.

1. Literature review on botanical explorations and forest classification (the account is given in Dobremez, 1976; Shrestha *et al*., 2002)
2. Transect walks across mountain slopes to observe the distribution of vegetation patterns (the account of the travels of the contributors is given in Dobremez, 1976; Shrestha *et al*., 2002)
3. Identification of vegetation types including general climatic relationship with mountain geography (account given in Dobremez, 1976; Shrestha *et al*., 2002)
4. Checking of plant species along transects through checklists/herbarium techniques (account given in Dobremez, 1976; Shrestha *et al*., 2002)
5. Preliminary synthesis and generation of hypotheses (account given in Dobremez, 1976; Shrestha *et al*., 2002)
6. Transferring information on medium scale maps (1:250,000) (account given in Dobremez, 1976; Shrestha *et al*., 2002)

The main aim of the mapping of Nepal was to provide a base for ecological characterisation of Nepal - both stable and unstable characteristics of vegetation was incorporated - but emphasis was given to the climatic climax of the vegetation type, not only to describe the distribution of natural vegetation, but also include human dimensions in the description.

Dobremez and his co-workers attempted to describe and characterise the ecological units (vegetation types) as the containers of different ecosystems (natural, semi-natural or man-made) and the natural vegetation as one of the contents in the container. The concept of iso-potential zones[3] was the basis for all the work by Dobremez (1976), the iso-potential ecological zone is a part of the landscape within which the environmental conditions varies less or are stable, as such it is mainly defined by homogeneity in physical factors, biological factors and human factors.

Dobremez (1976) considered the concept of iso-potential zones a more inclusive and more complex concept than the concept of biotope or ecosystem, which are only concerned with living animals and vegetation. It is also a more complete description than the more vague concept of 'natural environment' which generally excludes any influence of humans. The iso-potential zone is defined by its limits and its ecological content and the two points define two methods of delimitation.

Dobremez (1976) saw his method as deviating from the Zurich-Montpellier school in that he preferred to estimate the limits of the iso-potential zones before analysing their content. The analytical method of the Zurich-Montpellier school mainly consists of a systematic definition of the values of variables

[3] Iso-potential means that areas within the zone potentially has the same environmental conditions and therefore potentially would the same vegetation whatever the present condition of the forest. In the present paper iso-potential zones will be called Ecological Zones or vegetation Types.

(vegetation plots) at randomly chosen points and testing the homogeneity of these points. As such their method determines the content before determining the limits.

Dobremez and his co-workers made systematic plots in as large a number as possible in the forests. The work included analysis of the ecology of the points, an ecological analysis of the vegetation (stratification, density, and height) and a complete list of higher plants. The main difference to the Zurich-Montpellier school was the emphasis on providing a complete coverage of Nepal and thereby classifying the human part of the landscape by their potential vegetation types.

Seven maps were produced at the scale of 1:250,000 to cover the whole of Nepal. Fieldwork was carried out mainly by the French scientists J.F. Dobremez, and C. Jest; and Nepalese scientists T.B. Shrestha, P.R. Shakya, and D.P. Joshi. The US Army map at the scale 1:250,000 was used as the base map in the field (Shrestha *et al*., 2002).

Types of vegetation were classified on the basis of species dominance. Natural limits of vegetation (vertically and horizontally) were carefully detected in the field, and plant specimens were extensively collected for botanical identification. The extent of each vegetation type was plotted as per the concept of 'iso-potential zone'. The cartographical section of the Laboratoire de Biologie Vegetale, Grenoble undertook the responsibilities of preparing the map under the guidance of J. P. Guichard. All maps were prepared manually with traditional cartographic methodologies (Shrestha *et al*., 2002).

2.2.1.3 TISC: T.B. Shrestha and co-workers

TISC gave Dr. T.B. Shrestha the task of updating and supervising the digitisation of the Dobremez maps. The maps provided a base for a detailed classification of Nepal's ecosystem diversity. However, a holistic ecological picture of Nepal was far from complete as ecological details of different maps showed considerable variation.

Cultivated land was not uniformly converted into their corresponding vegetation types in the different maps. Colour coding lost consistency as the printing process had developed in time. The nomenclature differences for vegetation types in different maps remained unsolved.

The Biodiversity Profile Project (BPP, 1996) had attempted to digitise (with MENRIS, ICIMOD) the 7 maps of Dobremez and his co-workers. During the process the number of vegetation types was reduced - by BPP also called ecosystems and defined as distinct biological communities - from 136 to 118. The reduction was done by combining a number of vegetation types with largely similar species compositions. When the 7 maps were digitised the digital map showed clear edge-differences.

Between 1998 and 2000 TISC collaborated with the original Nepalese co-authors of the Dobremez hard copy maps under the guidance of Dr. T.B. Shrestha (first through a contract with IUCN Nepal and later directly) to pro-

duce a digital version of the Dobremez maps. The main work carried out was overlay of the maps onto a contour base map of Nepal (provided by MENRIS, ICIMOD), merging the separate maps, and incorporating vegetation classifications by other authors, prominent of which were Stainton (1972) and a score of Japanese researchers. The final number of forest types became 36.

The inconsistencies of different maps that appeared especially at their edge matching were removed through careful revision of vegetation types. The inaccuracies and errors in the earlier base map (Indian Survey Map, Quarter inches series, Survey of India, 1914-1926 and the U.S. Army Map Service 1: 250,000) were rectified and made consistent to the HMG Topographical Zonal Maps (1995) at the scale 1:250,000. In addition MENRIS digitised the 1000 feet (305 meters) height curve from the Indian Survey Map. The digitisation error is 0.55% of the total area (Rabin Shrestha, TISC).

The creation of the Potential Vegetation Map has gone through 4 steps.

1. Reconciliation of the Dobremez hard copy maps
2. Merging of forest types from the hard copy maps
3. Update and integration of phytosociological work and associated literature
4. Verification of the map through checking against plots and quadrant samples published in botanical/forestry literature

3 A new climate classification of Nepal

3.0.1 Matching the weather stations with the Potential Vegetation Map

TISC collaborated with the author of the Potential Vegetation Map and the Senior Divisional Meteorologist of Department of Hydrology and Meteorology in combining the information from the Potential Vegetation Map with the meteorological information from 261 stations. A ridge map of the country was also used to interpret the extension and distribution of rain-shadows.

The elaboration of the combined map of Vegetation/Ecological Zones and Climate (see Map 1) led to some corrections and new interpretations in the distribution of the vegetation types of the original map and on the other hand the distribution of vegetation types and ridges helped interpret the distribution of climate zones, especially for areas with insufficient weather stations.

Figure 1. Tropic of Cancer relative to Nepal

Floristically the Lower Tropical Ecological Zone of Lower Tropical Sal and Mixed Broad Leaved Forest corresponds to the North Indian Moist Deciduous Forest (Champion and Seth, 1968) and has recently been proposed by Ashton (1995) - as part of a regional classification of lowland forests of tropical Asia – to be a Tropical Deciduous Forest (fire tolerant). Floristically the Lower Tropical Ecological Zone therefore belongs to the tropics although the area is outside the Tropic of Cancer (see figure 1).

Bio-temperature has been used by Holdridge (Leemans, 1990) to classify the American continents into life zones. Using Holdridge's classification criteria the weather stations data in Nepal was used to accord stations in the ecological zones/height intervals (see table 1) to Holdridge life zones (Nayaju, 2000).

As shown in table 1, most stations in the Lower Tropical Zone fall in the Holdridge tropical life zone. Nearly all stations in the Upper Tropical Zone fall in the Holdridge Sub-tropical life zone. Nearly half the stations in the

Sub-tropical Zone fall into the Holdridge Sub-tropical and the other half in Holdridge Warm Temperate. Most stations in the Temperate Zone fall in Holdridge temperate and Warm Temperate life zones. The Stations in the Sub-alpine and Trans-Himalayan Zones fall mainly in Holdridge Temperate life Zones.

Table 1. Comparison of Ecological Zones to Holdridge Life Zones

Ecological Zone	Holdridge Life Zone	No of Stations
Lower Tropical	Sub-tropical	8
Lower Tropical	Tropical	58
Upper Tropical	Sub-tropical	48
Upper Tropical	Tropical	1
Upper Tropical	Tropical	1
Sub-tropical	Sub-tropical	48
Sub-tropical	Warm Temperate	56
Temperate	Sub-tropical	1
Temperate	Temperate	10
Temperate	Warm Temperate	14
Sub-alpine	Boreal	3
Sub-alpine	Temperate	7
Trans-Himalayan	Temperate	3

Source: Nayaju & Lillesø (2000). Note: 258 stations were used

Considering that the Holdridge life zone system was elaborated for the Americas and cannot be directly transferred to the Himalayan area without modifications, a classification starting with a lower tropical zone rather than a subtropical zone is reasonably well justified.

3.1 General climate

Although Nepal lies near the northern limit of the tropics, because of rugged topography, there is a very wide range of climates, from the summer tropical heat and humidity of the lowlands to the colder dry continental and alpine winter climate through the middle and northern mountainous sections.

During Northern Hemispheric summer, the southeast trade wind blows from the Southern Hemisphere, due to an intense pressure gradient towards India. In Nepal the monsoon air masses advance from east to west, and the level of maximum moisture advection[4] will increase due to orographic[5] ascending of monsoon air masses. In the eastern lowland this level is below 1500 meter and when it arrives in Kathmandu valley it is raised to 3000 meter above mean sea level (Nayaju, 2000). Hence the precipitation distribution will be different for the same height barrier for different location.

[4] Advection: the process of transport of an atmospheric property solely by the mass motion of the atmosphere

[5] Orographic: orogenic belts consist of rocks that have been intensively folded, thrust long distances horizontally, often metamorphosed, intruded with granites, and elevated or uplifted to form mountain chains. Orographic ascending air masses are forced upwards by mountain chains.

3.1.2 Effect of topography on soil water and water profile

Topography plays a most important role in modifying climate, weather, precipitation distribution and soil properties; hence proper land use management should be conducted in order to insure a sustainable development. Car-

son (1992b) has described the effect of topography on the soil and water profile and land use management, and the types of soils in Nepal have been described in Carson, Shah & Maharjan (1986). The relationship between slopes and soil can very generally be described as follows (adapted from Kohnke, 1968).

Soils of flat upland with slopes up to 2% have only little runoff under pristine conditions. The amount of infiltration plus evapo-transpiration is nearly the same as precipitation. Clay is washed into the B-horizon forming a clay pan. Sub-soils are acid because they are leached of bases and they may be mottled due to restricted drainage.

On soils of the medium slopes of about 4 to 15% some water from larger rainstorms is swept downhill taking dissolved mineral material with it. Clay formation in the B-horizon is not very pronounced and internal drainage is therefore good. As these soils keep less water than they receive in the rain, they tend to be draughty.

Soils of steep slopes, steeper than 20%, have runoff and geologic erosion so pronounced that only little of the leached material of the surface soil enters the sub soil. Before any recognizable accumulation of clay in the subsoil can take place, the weathered surface soil is removed by geologic erosion and the newly exposed soil is leached out. In this way a soil profile with A and C horizon without a B-horizon is formed. Due to excessive runoff, the erosion hazard is great and these soils are adapted only to permanent vegetation.

With slopes of 0 to 1% soils of swales develop by receiving enriched seepage and runoff water from the surrounding upland in addition to direct rainwater. They are moist practically at all times and with abundant vegetation have a high content of organic matter. If well drained, they are very fertile. They are nearly neutral in reaction throughout the profile.

These soil and water profiles have profound effect on proper land-use management. A closer study and mapping of soils in relation to climate would add precision to the classification of soils and agro-climatic and agro-ecological zones. This in turn will help in the prediction of the possible consequences of the alternative use of land resources.

3.2 Potential Evapo-transpiration

Table 2 shows the average monthly water balances (mm) precipitation minus potential evapo-transpiration. The stations where sorted by Development Region (to obtain an east-west orientation) and by the moisture zone (from Arid Zone to Per Humid Zone) they belong to (as determined by their moisture index). There is a decreasing trend in the number of dry months from 12 in the Arid Zone down to 6 dry months in the Per Humid Zone), although at this level of analysis the length of the dry season is not consistently shorter in the Humid Zone as compared to the Semi-Arid Zone. An east-west trend toward more dryness in the west is not consistent (see also Map 1 for the map of weather stations and moisture regions).

Table 2. Average monthly water balances (mm) precipitation minus potential evapo-transpiration

Development Region	Climate Zone	Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum	Dry Months
West	Arid	5	-47	-45	-69	-93	-112	-105	-64	-58	-66	-61	-59	-50	-826	12
Eastern	Semi Arid	14	-46	-64	-103	-106	-48	64	176	98	60	-49	-69	-57	-146	8
Central	Semi Arid	20	-40	-58	-101	-123	-92	44	200	138	69	-51	-69	-49	-132	8
West	Semi Arid	9	-38	-42	-72	-103	-92	39	198	136	67	-45	-65	-47	-63	8
Mid West	Semi Arid	24	-29	-41	-81	-123	-119	-17	142	121	28	-71	-78	-50	-319	9
Far West	Semi Arid	9	-22	-38	-93	-139	-113	18	207	179	59	-72	-76	-44	-142	8
Eastern	Humid	34	-39	-53	-80	-78	-3	160	309	234	152	-11	-58	-49	481	8
Central	Humid	42	-37	-50	-84	-88	-35	151	328	276	152	-29	-59	-43	490	8
West	Humid	25	-31	-45	-80	-91	-27	158	352	266	146	-34	-61	-38	515	8
Mid West	Humid	13	-29	-47	-98	-130	-108	95	320	299	137	-50	-67	-42	288	8
Far West	Humid	20	-11	-22	-70	-122	-102	81	334	311	129	-59	-68	-37	362	8
Eastern	Per Humid	14	-32	-31	-40	-25	77	308	485	383	274	30	-40	-40	1347	6
Central	Per Humid	14	-32	-38	-54	-50	20	305	577	554	285	1	-49	-39	1467	6
West	Per Humid	16	-27	-23	-39	-31	103	405	691	631	379	30	-43	-32	2058	6
Mid West	Per Humid	1	-30	-25	-65	-92	-5	256	525	531	189	-14	-50	-44	1269	8
Far West	Per Humid	1	-17	-9	-47	-29	30	172	459	500	242	-42	-39	-16	715	7

Source: Nayaju & Lillesø (2000)

3.3 Temperature Regions

Mean Annual Temperature has a profound effect on forestry and agricultural systems; it is greatly influenced by altitude, accounting for more than 90% of the variability in the observed temperature data in Nepal (Nayaju, 2000).

The weather stations were stratified according to the ecological zones to obtain average monthly temperatures for each zone. In figure 2 the averages for each zone is plotted against months, while in table 3 the data is further separated into climate zones within ecological zones to show some of the variation. The data will inherently show some variation as the weather stations are not evenly distributed within the ecological zones and many stations occur on borders between the zones. Nevertheless, there appears to be a good overall correspondence between temperature and ecological zone. This is to be expected as temperature generally varies along with elevation.

Figure 2 shows a clear difference between the average monthly temperatures between the Ecological Zones. This is to be expected as the temperature is very much dependent on altitude.

Table 2 shows the same picture and a closer analysis may confirm that the wetter regions are slightly cooler than drier regions (more cloudiness).

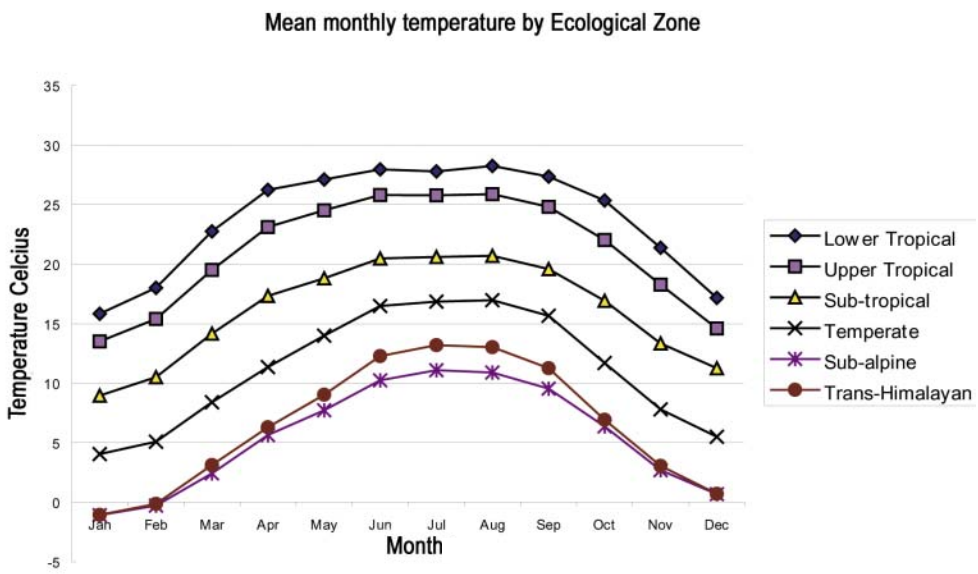


Figure 2. Mean monthly temperature by Ecological Zone

Table 3. Average monthly temperature (°C) by Ecological Zone and Climate Zone

Ecological Zone	Moisture Region	Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Lower Tropical	Semi Arid	31	16	18	23	27	29	30	29	29	28	26	22	17	24
	Humid	34	16	18	23	27	29	30	29	29	28	26	21	17	24
	Per Humid	2	16	18	23	26	27	28	28	28	27	25	22	18	24
Upper Tropical	Semi Arid	14	14	16	20	24	26	27	27	27	26	23	19	15	22
	Humid	27	14	16	21	25	27	28	27	27	26	23	19	15	22
	Per Humid	9	14	15	20	23	25	26	26	26	25	22	18	15	21
Sub-tropical	Semi Arid	20	10	12	16	19	21	23	23	23	21	18	15	11	18
	Humid	61	10	12	16	20	22	23	23	23	22	19	15	12	18
	Per Humid	25	9	11	14	17	19	20	21	21	20	17	13	50	16
Temperate	Arid	2	4	5	8	11	14	17	18	18	16	12	8	6	11
	Semi Arid	7	5	6	9	13	16	19	19	19	17	13	9	6	13
	Humid	8	6	8	11	15	17	19	19	19	18	15	11	8	14
	Per Humid	8	5	7	10	13	14	16	17	17	16	13	9	7	12
Sub-alpine	Semi Arid	4	1	2	5	8	10	13	14	14	13	9	5	3	8
	Humid	4	-1	0	2	6	8	10	11	11	10	6	3	1	5
	Per Humid	2	1	1	4	8	10	13	13	13	12	8	4	3	7
Trans-Himalayan	Arid	3	-1	0	3	6	9	12	13	13	11	7	3	1	6

Source: Nayaju & Lillesø (2000)

3.3.1 Frost

When moist air is cooled below 0°C water vapour may be deposited as an ice, called frost, on certain solid objects. The main causes of frost are the nocturnal radiation and restriction of air drainage.

In the valleys, frost is formed by integrated duel processes, one by nocturnal radiation cooling of valley air and the other by the drainage of cool air from around the hills and mountain slopes at night. On the ridges, it is formed either by nocturnal radiation cooling or through the contact of cool surface with moist air advected by light wind or by both processes.

Slope aspects also play an important role in the frequency and duration of frost. The frequency and duration of frost on northern slopes is higher than on southern slopes. Since air drainage system is better on a ridge than in valleys, frequency of frost on ridges is lower than in the valleys. As for example, Khumaltar (in the valley) at 1350 m, on the average, experiences 16 frost days per annum, whereas, Kakani, (on the ridge) northwest of Kathmandu at 2064 m experiences only 9 frost days per annum. Similarly Kathmandu Airport (in the valley) at 1337 m observes 10 days per annum, whereas Nagarkot (on the ridge, east of Kathmandu valley) at 2163 m observes only 5 days per annum. Although the frequency is very small, frost has been observed even at elevation 823m (Khudibazar), whereas Rukumkot (2100m) has yet to experience frost (Nayaju, 2000).

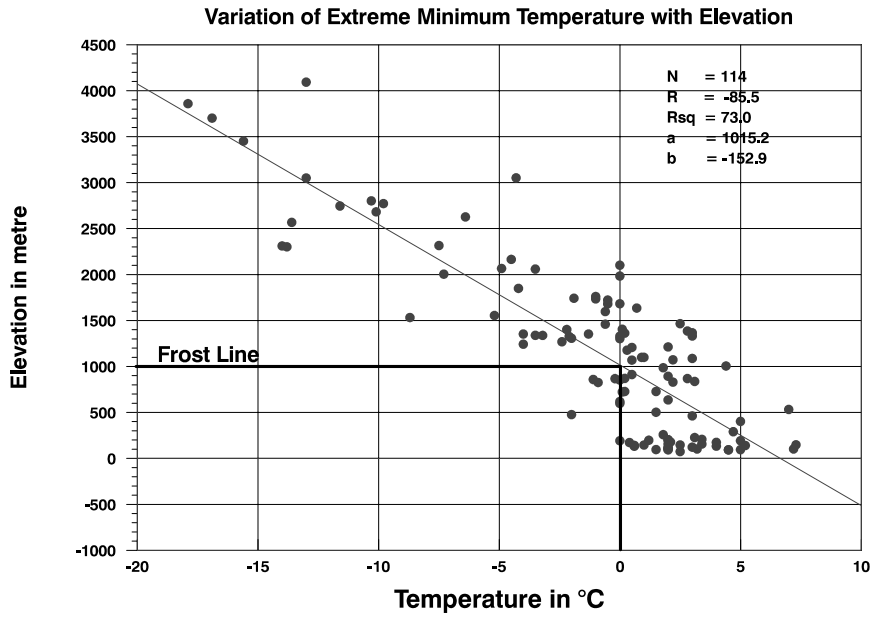


Figure 3. Regression of of elevation and Temperature to estimate 'frost line'. N= number of weather stations, R= regression coefficient, Rsq=Coefficient of determination, a=intercept, b=slope (Nayaju, 2000).

It is clear from these facts that occurrence of frost is a quite complex phenomenon. It depends upon many factors such as geographical position, ridge, valley, slope aspect, elevation moisture availability, and soil characteristics. However, an average frost line for Nepal can be estimated from temperature and elevation data using correlation analysis.

As defined above, frost is formed when moist air is cooled below zero degrees centigrade. Hence, it is clear that zero degree is the boundary value and the elevation that crosses the zero degree can be called a frost line. From the regression in figure 3 this elevation is 1015m and a general frost line for Nepal may be said to be around 1000m elevation.

3.4 Moisture Regions

Considerable variations in precipitation are observed due to the presence of exceptionally rugged terrain. The minimum density norm, recommended for the hilly region by the World Meteorological Organisation for pluviometric networks (made-up of ordinary rain gauge) is 100 to 250 per km^2 i.e. about 600 to1500 stations would ideally be required in Nepal (Nayaju, 2000). For a large number of reasons (economical, topographical, climatological and constraints of permanent settlement of competent observers) only about 270 stations have been installed. From the station distribution map (see Map 1) it is clearly visualized that station density, especially in the north-western sectors of the country, is very sparse. For the analysis of precipitation, available data from 261 stations that has at least 10 years of records have been used (Nayaju & Lillesø, 2000).

About 80% of total precipitation falls during monsoon (June to September); about 15% falls during pre-monsoon (March - May) and post monsoon (October); and less than 5% falls during winter (Nov.-Feb). It is observed that July is the wettest month and November is the driest month of the year. As the summer precipitation (monsoon) advances from east to west so the winter precipitation advances from the west to east but its extension and intensity is so weak compared to summer monsoon that its appreciable effect is limited to Mid Western and Far Western regions. The average precipitation in Nepal is 1800 mm and its distribution ranges from less than 250 mm in the north-central portion near the Tibetan plateau to more than 5000 mm in along the southern slopes of Annapurna Range in central Nepal (Nayaju, 2000).

In Figure 4 the weather stations have been sorted according to Moisture Zone and in Table 4 the weather stations have been sorted according to Ecological Zone as well as Moisture Zone.

The differences in the yearly amounts of precipitation received in the different Moisture Zones are evident. However, as table 2 shows, the big differences in precipitation become less significant in terms of overall moisture availability to crops when average monthly water balances are taken into account. The differences in impact on erosion are, however, evident.

Of the two kinds of profiles, Thermal Profile and Moisture Profile, Thermal Profile is quite consistent with topographic altitude, whereas the same topographic altitude has a complex distribution for Moisture Profile. The following tables 5a and 5b give the thermal and moisture profile as well as temperature extremes for of the ecological zones.

Table 4. Average monthly precipitation (mm) by Ecological Zone and Climate Zone

Ecological Zone	Climate Zone	Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Lower Tropical	Semi Arid	31	19	18	16	30	81	213	416	333	223	57	6	11	1,427
	Humid	34	18	18	19	37	108	310	574	454	319	81	9	13	1,960
	Per Humid	2	14	19	24	58	230	502	781	553	477	135	21	11	2,792
Upper Tropical	Semi Arid	14	23	24	28	39	85	188	291	254	151	44	8	14	1,153
	Humid	27	23	24	29	51	127	317	511	437	290	71	10	13	1,900
	Per Humid	9	22	30	53	87	228	544	794	700	471	131	17	13	3,085
Sub-tropical	Semi Arid	20	29	31	42	47	83	163	268	216	136	46	9	14	1,080
	Humid	61	25	28	38	58	124	275	430	394	234	63	11	15	1,700
	Per Humid	25	23	34	55	92	207	490	763	705	433	110	21	17	2,937
Temperate	Arid	2	11	13	26	23	25	31	52	52	45	36	7	4	327
	Semi Arid	7	31	44	64	49	59	88	193	184	112	41	10	16	893
	Humid	8	27	33	44	56	105	261	450	409	237	57	14	16	1,699
	Per Humid	8	24	33	54	76	159	423	705	667	392	94	19	14	2,703
Sub-alpine	Semi Arid	4	35	35	52	39	56	83	172	172	95	32	10	22	808
	Humid	4	44	47	64	51	48	134	213	208	132	59	11	19	1,061
	Per Humid	2	30	42	61	63	131	275	473	500	311	62	16	16	1,922
Trans-Himalayan	Arid	3	9	11	10	6	7	14	54	56	23	17	3	8	223

Source: Nayaju & Lillesø (2000)

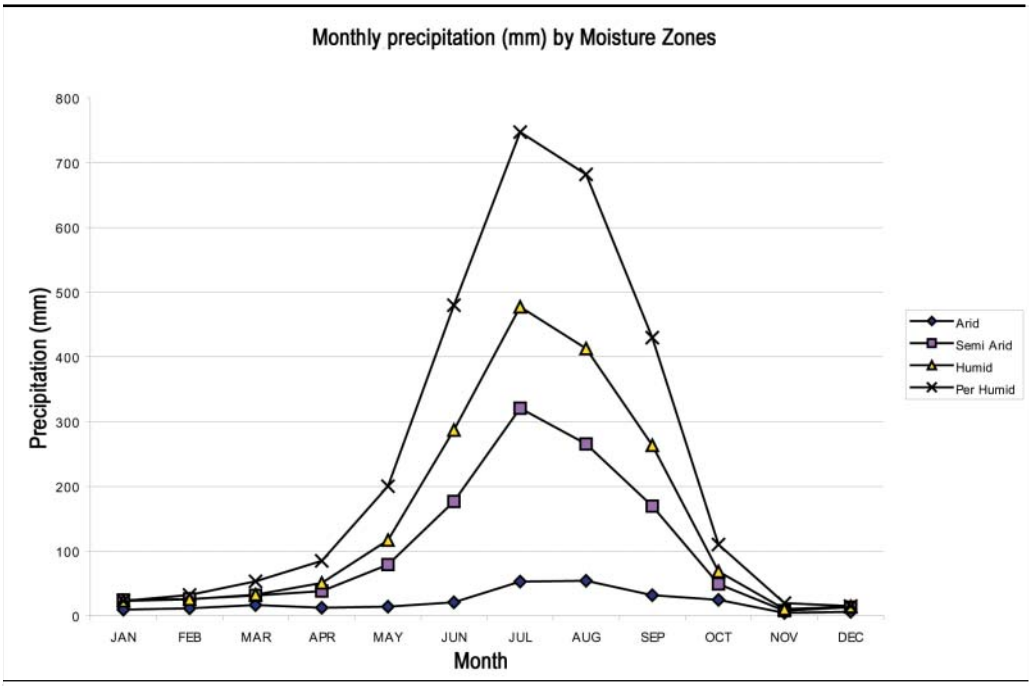


Figure 4. Monthly precipitation by Moisture Zone

Alternate maxima and minima in the windward side (southern slopes) and leeward side (northern slopes) respectively along the hills and mountains are found with varying scale of depth in relation to height of the barrier, height of maximum advection level with the scale of depression in the Bay of Bengal (Nayaju, 2000).

Table 5a. Thermal and moisture profiles of the Ecological Zones

Ecological Zones	# of Stations	Altitude Ranges (m)	Mean Temp. Ranges °C	Mean Temp. °C	Precipitation Extremes (mm)	Mean Precipitation (mm)
Lower Tropical	67	- 300	23.0-25.5	24.1	1,159 – 2,827	1738
Upper Tropical	50	300 - 1000	20.0-23.0	22.0	947 – 3,867	1904
Sub-tropical	106	1000 - 2000	15.0-20.0	17.6	591 - 5,284	1875
Temperate	25	2000 - 300	10.0-15.0	12.7	262 - 3,949	1685
Sub-alpine	10	3000 - 4000	5.0-10.0	6.9	440 - 2,131	1132
Alpine	0	4000 - 5000	-	-	-	-
Trans-Himalayan	3	3000 -	-	6.5	157 - 339	223

Source: Nayaju (2000)

Table 5b. Temperature extremes: min/avg/max by Ecological Zones (°C)

Ecological Zones	Days >30 ˚C	Max Temp (˚C)	Days < 0˚C	Min Temp (˚C)
	Min - Max	Min - Max	Min – Max	Min - Max
Lower Tropical	199 - 246	41 - 46	Less than 1/10	0 - 5
Upper Tropical	62 – 215	35 - 45	Less than 1/10	-2 – 7
Sub-tropical	0 – 173	29 - 40	0 – 53	-9 – 4
Temperate	0 – 47	23 - 42	0 – 132	-14 – 0
Sub-alpine	None	20 -26	145 - 229	-18 – (-13)
Alpine	-	-	-	-
Trans-Himalayan	None	-	195	-26

Source: Nayaju & Lillesø (2000)

3.4.1 Moisture index

Moisture index as used by Thornthwaite in his 1948 climatic classification is a measure of precipitation effectiveness for plant growth which takes into consideration the weighted influence of water surplus (humidity index) and water deficiency (aridity index) as related to water need and as they vary according to season (details are given in Nayaju & Lillesø, 2000).

For the climatic classification of Nepal the following values were used for a very simple climatic classifications in terms of moisture index:

Ranges of Moisture Index	Climatic Classification
Arid	-60 to -40
Semi-Arid	-39 to +20
Humid	+21 to +100
Per-Humid	>+100

The climate zoning was superimposed on the Potential Vegetation Map following the ridges, and weather stations. 10 stations out of 261 stations do not fit into the system. For six of these stations their index values are bordering the climate zone that they are placed within. The remaining 4 stations have values that are much to high or low compared to the zones that they are placed within. It will be investigated if the problem lies in data collection from the stations (probable with station #806) or if the stations represent true localized aberrations in climate (Nayaju & Lillesø, 2000).

4 Physiographic classification in Nepal

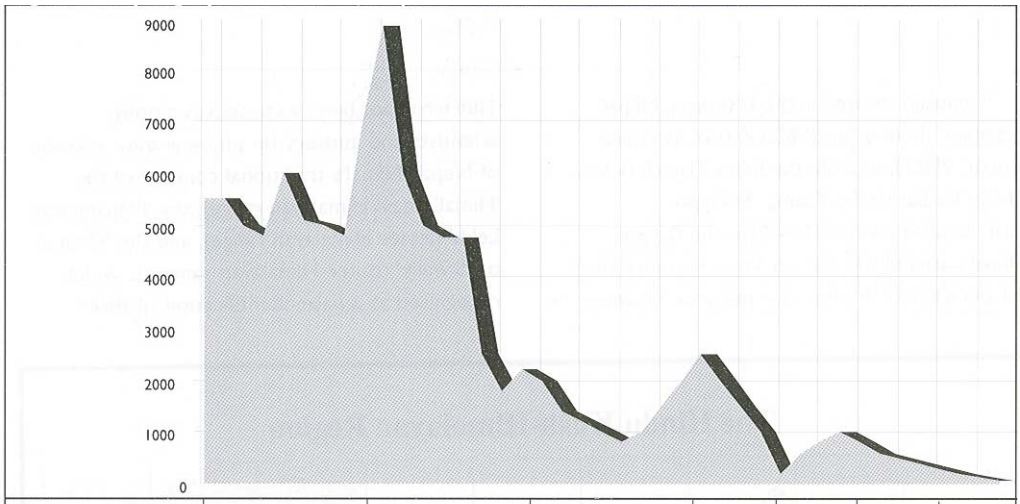
The most widely used way of classifying Nepal is a physiographic classification system: Tarai, Hills and Mountains. This has been used to group districts with similar characteristics and administratively Nepal has been divided into five Development Regions and in 75 districts as shown in table 6. The 75 administrative districts have been divided into three physiographic regions to indicate the remoteness as well as the difficult terrain. The 16 High Mountain Region districts represent the most remote and difficult terrain in the High Himalayan range. The 39 hill districts have comparatively gentle slopes and less remote areas. The 20 Terai districts are more accessible and lies in the flat land of Terai.

In the 1980's the Land Resources Mapping Project further detailed the physiographic classes into: Tarai, Siwaliks, Mid-Hills, High Mountains and High Himalayan (LRMP, 1986), see figure 5 and Map 2.

Table 6. Physiographic Regions of Nepal Based on Administrative Districts

Development Region	Zone	Administrative Districts (75 Districts)		
		Tarai	Mid-Hill	Mountain
Eastern	Mechi	Jhapa	Ilam, Panchthar	Taplejung
	Khoshi	Morang, Sunsari	Dhankuta, Terhathum, Bhojpur	Sankhuwasabha
	Sagarmatha	Saptari, Siraha	Udaypur, Khotang, Okhaldhunga	Solukhumbu
Central	Janakpur	Dhanusha, Mahottari, Sarlahi	Sindhuli, Ramechhap	Dolakha
	Narayani	Rautahat, Bara, Parsa, Chitwan	Makwanpur	-
	Bagmai	-	Kathmandu, Bhaktapur, Lalitpur Nuwakot, Dhading, Kabhrepalanchok	Sindhupalchok, Rasuwa
Western	Lumbini	Nawalparasi, Rupendehi, Kapilvastu	Palpa, Arghakhanchi, Gulmi	-
	Gandaki	-	Tanahu, Syangja, Gorkha, Lamjung, Kaski	Manang
	Dhaulagiri	-	Parbat, Baglung, Myagdi	Mustang
Mid-Western	Rapti	Dangdeukhuri	Pyuthan, Rolpa, Salyan, Rukum	-
	Bheri	Banke, Bardia	Surkhet, Jajarkot, Dailekh	-
	Karnali	-	-	Dolpa, Jumla, Kalikot, Mugu, Humla
Far-Western	Seti	Kailali	Achham, Doti	Bajura, Bajhang
	Mahakali	Kanchanpur	Dadeldhura, Baitadi	Darchula
5 Dev. Regions	14 Zones	20 Districts	39 Districts	16 Districts

Source: IUCN 2000



Gurung, H.B. (1960) Native Terms	Bhot	Himal		Pahad	Mahabharat	Madhes	Chure	Tarai
LRMP (1986) FSMP (1989)	High Himalaya		High Mountains	Mahabharat		Siwalik		Tarai
Hage, T. (1960)	Tibetan Marginal Mountains and Inner Himalaya	Himalaya		Midlands	Mahabharat	Siwalik		Tarai
Ives and Messerli (1989)	Tibetan Marginal Mountains and Inner Himalaya	Greater Himalaya	Transition Belt	Middle Mountain	Mahabharat	Siwalik		Tarai

Figure 5. Descriptions of a cross section of Nepal (Shrestha et al., 2002)

A general description of the physiographic zones is as follows (but see below in 5.3.2 for an analysis of the accuracy of this general description): the Terai region comprises 14% of the land area of Nepal, elevations range from 60 to 330 meters, with slope gradients from 0.2 to 1%; the land is flat, with the exception of minor local relief caused by river action. Siwaliks cover approximately 12.7% of the land area; relief of less than 300 meters is common and rarely exceeds 1000 meters. The Mid-Hills (Middle Mountains) cover approximately 29.5% of the land area; relief of up to 1000 meters is common, between valley bottom and adjacent hilltops, while maximum relief of 2000 meters occur in the southern part. The High Mountains make up approximately 19% of the land area; relief in the order of 2000 meters is common. The High Himalayan (Himal) occupies roughly 23.7% of the land area; relief is commonly over 3000 meters (Carson & Sharma, 1992).

5 Requirements of an ecological classification

The purpose of an ecological classification from a utilitarian point of view is that the classification can provide meaningful information for the planning and implementation of land-use.

The ecological classification therefore has to identify units in the field that are homologous internally and different from other units in some important aspects. This has been exceedingly difficult to establish in Nepal due to the enormous variation in the country. However, with the advent of inexpensive computing power and user friendly mapping software the task has become less daunting than it was even a few years ago, and with the large amount of localised and more generalised data accumulated by researchers in Nepal over the past decades an ecological map of use to many types of land-use planning can be made with reasonable accuracy.

5.1 Simple but not simplistic and developed within an open framework

In Nepal, if ecological maps attempt to portray all recognized differences in landscape characteristics including slope, elevation, total rainfall and its distribution, soil type, micro climate, associated with mature phase and early phase vegetation no planner will be able to grasp how they can be used and certainly no layman can understand them (Carson & Sharma, 1992).

The ecological classification therefore has to differentiate the major differences only, while allowing for variation within each class.

The Potential Vegetation Map is a digital system that can be continuously updated and improved as planners, researchers and extension agents become familiar with the basic classification system and through its use requirements for improvements will be identified.

5.2 Based on criteria that are relevant to forestry, agriculture and natural resource conservation

The Potential Vegetation Map is based on the natural distribution of vegetation types and as such is very suitable for natural forest management - which is one of the major objectives by the Community Forestry Programme in Nepal – and to natural resource conservation/ biodiversity conservation. However, details of individual species' distributions are still insufficiently known[6], as well as preferences for their uses by local communities are still inadequately known[7].

Preliminary maps of crop-wise potential cropping areas have been prepared by TISC (through a contract with IUCN Nepal). These maps have to be further refined based on the recent climatic mapping elaborated as part of the eco-

[6] Each species has its own individualistic distribution within vegetation types, by altitude and east to west of the country.

[7] Human use of and preference for species depends on the species quality relative to other available species as well as cultural and socio-economic preferences.

logical classification and based on a mapping of the farming systems of the country[8], and for more detailed planning more detailed height contours must be included into the base map.

5.3 Some interpretations from the map

The Potential Vegetation Map is the first map of Nepal that has an ecological classification for the whole country in one digital map[9].

The Potential Vegetation Map does not take into account actual land use (and is not intended as such) but can readily be combined with land-use maps derived from aerial photography and satellite images. The Land Resource Mapping Project (LRMP, 1986) was the first major attempt at mapping the actual land use in Nepal and much of the information produced by that project can still be used and supplemented by more recent information e.g. DFRS (1999).

5.3.1 Distribution of settlements in Nepal

The advantage of using the Ecological Zoning as compared to the Physiographic Zonation can also be seen from the overlay of settlements in Nepal onto the Ecological Zones and Physiographic Regions. Map 3 shows that at higher altitudes (from Sub Tropical Zone and upwards) the settlement pattern follows the valley systems that in the delineation of Physiographic Regions are included in the broad regions of High Mountains and High Himal respectively.

The overlay of settlements on the Ecological Zones also indicates that it is in the Tropical and Sub-Tropical Zones where most of the people of Nepal live, even in the so-called Mountain Districts (see also tables 7, 8, 9, 10 11, and 12).

5.3.2 The physiographic classification

The delineation into physiographic regions has provided a very useful tool for planners. However, as the map of Nepal in Map 2 shows, each of the Physiographic Zones has a large internal variation (relief) and the classification ignores a considerable heterogeneity within each physiographic region - in particular the Dun valleys of the Siwaliks and the tropical valleys and elevated plains of the Middle Mountains Region. The subtropical valleys of the High Mountains, and the dry trans-Himalayan area in the High Himalayan Region are disregarded in this classification, and the classification therefore has some limitations for identifying options for forestry, agriculture, and for distributions of animals and plants.

The underlying topographic base map for the Potential Vegetation Map corresponds quite closely to the maps of the Land Resources Mapping Project (LRMP, 2000) for the areas covered by the Physiographic Regions, however, the classification of altitudes for each of the physiographic regions are very different. The Potential Vegetation Map shows that the physiographic regions have very large overlaps in altitudes, mainly due to the inclusion of valley systems in all the physiographic regions (see also Map 2).

[8] HMG/Danida Tree Improvement and Silviculture should initiate this work for individual crops as well as for farming systems.

[9] A map was however made by the Topographical Survey Branch, Survey Department, HMG showing both rainfall distribution and physiographic zones (Anonymous, 1985). It appears not to have been used widely and the underlying documentation could not be traced.

Table 7. Overlapping altitudes in the physiographic zones

	Extracted from the Topographic Base Map		Estimated by LRMP	
Physiographic Region	**Area (sq. km)***	**Altitude****	**Area (sq. km)**	**Altitude**
High Himalayan	35,230	2000-8500m	33,492	Above 4000m
High Mountain	30,004	1000-5500m	29,594	2200-4000m
Middle Mountain	42,904	300-3000m	44,436	800-2400m
Siwalik	18,910	300-1500m	18,858	200-1500m
Tarai	20,130	Below 500m	21,104	60-300m

Sources: TISC; IUCN (2000). Note: *The error of the base map of 0.55% has been evenly distributed to the areas. **The altitudes are the highest and lowest height curves within the Physiographic Regions.

The administrative classification of districts into 3 physiographic groups (see table 6) is too much of a simplification – from the point of view of natural resources management – as no districts belong fully to one of the groups. In map 4 the district grid has been overlaid on the Ecological Zones and as can be seen, Tropical and Sub-tropical climates occur in most of the hill districts. Even mountain districts like Taplejung, Sankhuwasabha, Dolakha, Sindhupalchok and Dhading have a strong representation of tropicality.

Tropical diseases like malaria and encephalitis not only occur in Tarai, but also in Mid-Hill and Mountain districts and tropical crops like rice, sugarcane, banana and mango grow in most districts. Some hill districts like Gorkha have a range of ecological regions from Tropical to Nival (Artic) Zone as well as the Trans-Himalayan Arid Zone.

The classification of the 75 districts into Tarai districts, Mid-Hill Districts, and Mountain districts in a very broad sense follows an altitudinal gradient, however, the classification ignores considerable variation within each class as can be seen by the tables of individual districts (see also Map 4 and Map 5).

Table 8. Percentage of Ecological Zones within the classes Tarai, Hill, and Mountain districts

Districts Total	Lower Tropical Zone %	Upper Tropical Zone %	Sub-Tropical Zone %	Temperate Zone %	Sub-Alpine Zone %	Alpine Zone %	Trans-Himalayan Zone %	Nival Zone %
Tarai	73.4	21.6	4.0					
Hill	2.7	29.1	41.9	14.2	5.7	3.1	1.0	1.9
Mountain		1.6	10.8	17.5	18.2	18.6	20.2	12.9

Source: TISC Map and database. Note totals are less than 100%, but more than 99.9% due to rounding errors and waterbodies not included.

Nearly all the Tarai districts contain a large but varying proportion of Upper Tropical Zone, and some districts also contain a significant proportion of Sub-Tropical Zone, see table 9. The Mid-Hill districts cover all the Ecological Zones of Nepal with varying proportions of zones in each district. Examples of extremes of Mid-Hill districts are Gorkha district that covers all the zones, while Bhaktapur district only covers two zones.

Three districts - from separate physiographic zones - are shown in Map 5 to illustrate that the physiographic classification provides too little information on the potential of districts.

Table 9. Tarai Districts and Ecological Zones (elevation)

Districts	Lower Tropical Zone %	Upper Tropical Zone %	Sub-tropical Zone %	Temperate Zone %	Water Body Zone %
Banke	79.1	20.6	0.3		
Bara	86.6	13.4			
Bardia	71.4	22.6	2.7		3.3
Chitwan	58.2	32.6	6.7		2.4
Dang	18.1	69.9	12.0		
Dhanusa	92.5	7.5			
Jhapa	98.8	1.2			
Kailali	59.3	25.9	13.8		1.0
Kanchanpur	85.2	13.0	1.8		
Kapilbastu	86.8	12.0	1.2		
Mahottari	85.0	15.0			
Morang	80.9	11.5	7.4	0.2	
Nawalparasi	56.2	34.9	5.7		3.3
Parsa	74.7	25.3			
Rautahat	94.4	5.6			
Rupandehi	89.3	10.5	0.2		
Saptari	94.7	2.4			2.9
Sarlahi	88.3	11.7			
Siraha	90.5	9.5			
Sunsari	86.6	7.8	2.0		3.6

Source: TISC Map and Database. Note: The "Water body" only calculates river deltas and some lakes.

Most Mid-Hill (hill) districts have a significant proportion of Upper Tropical Zone, and some even Lower Tropical Zone, see table 10 and also contain varying proportions of sub Tropical, Temperate, Sub Alpine, Alpine and Trans Himalayan Zones.

Table 10. Hill Districts and Ecological Zones (elevation)

Districts	Lower Tropical Zone %	Upper Tropical Zone %	Sub-Tropical Zone %	Temperate Zone %	Sub—Alpine Zone %	Alpine Zone %	Trans-Himalayan Zone %	Nival Zone %	Water Body %
Achham		27.4	58.3	12.2	1.0				1.2
Arghakhanchi	0.2	50.5	49.1	0.2					
Baglung		2.8	37.1	39.4	18.6	2.1			
Baitadi		13.1	71.2	15.7					
Bhaktapur			99.4	0.6					
Bhojpur	2.7	30.5	49.8	15.1	1.7				0.3
Dadeldhura	0.6	34.7	55.8	8.9					
Dailekh		16.7	64.5	16.1	2.3	0.0			0.5
Dhading	0.0	39.7	35.1	10.8	7.7	3.2		2.5	0.9
Dhankuta	3.7	44.7	46.6	3.2					1.7
Doti	0.1	22.2	58.8	17.6	1.2				0.1
Gorkha	0.1	19.8	14.6	13.3	14.9	10.6	14.8	11.5	0.2
Gulmi		23.5	71.9	4.6					0.0
Ilam	15.5	33.5	40.1	10.6	0.3				
Jajarkot		5.9	37.3	34.6	16.9	2.3		3.0	
Kabrepalanchok	0.1	23.6	65.3	9.6					1.3
Kaski		18.6	29.4	16.6	12.1	14.8	0.6	7.4	0.5
Kathmandu			88.2	11.8					
Khotang	0.7	31.5	49.1	16.3	1.6				0.9
Lalitpur		9.9	79.3	10.8					
Lamjung		18.5	34.0	20.3	14.1	8.0	1.3	3.6	
Makawanpur	7.2	59.0	28.9	4.9					
Myagdi		0.1	17.5	28.0	21.1	17.8	1.6	13.9	
Nuwakot		28.6	50.8	13.4	3.9	1.3		0.3	1.7
Okhaldhunga		22.2	51.1	24.2	2.1				0.5
Palpa	0.3	51.3	47.3						1.0
Panchthar		18.3	52.6	23.9	4.7	0.4			0.0
Parbat		17.8	66.9	14.0	1.4				
Pyuthan		36.1	53.3	9.7	0.8				
Ramechhap		18.0	42.1	21.0	6.7	3.6		7.3	1.3
Rolpa		3.3	61.7	31.4	3.6				
Rukum		2.9	26.0	32.6	23.0	14.9		0.7	
Salyan		28.6	68.3	3.0					
Sindhuli	13.7	61.7	23.6	0.5					0.5
Surkhet	2.2	61.9	32.8	1.3					1.9
Syangja		53.6	45.3	0.0					1.1
Tanahu	2.3	88.0	8.8	0.0					0.9
Terhathum		24.0	56.4	19.5	0.0				0.2
Udayapur	33.7	45.9	17.8	0.5					2.1

Source: TISC Map and Database. Note: The 'Water body' only calculates river deltas and some lakes.

The mountain districts cover all the Ecological Zones of Nepal (although only Sankhuwasabha has Lower Tropical and only 0.3%). There is a significant proportion of Subtropical Ecological Zone in most of the Hill districts. The Trans-Himalayan Zone is not recorded as a separate zone in the physiographic classification although the climate is profoundly different from the rest of Nepal; this zone is a significant proportion of some districts.

Table 11. Mountain Districts and Ecological Zones (elevation)

Districts	Lower Tropical Zone %	Upper Tropical Zone %	Sub-Tropical Zone %	Temperate Zone %	Sub-Alpine Zone %	Alpine Zone %	Trans-Himalayan Zone %	Nival Zone %	Water Body %
Bajhang		0.5	18.0	26.5	16.6	8.4		30.0	
Bajura		0.6	19.7	36.4	25.2	11.2	0.5	6.4	
Darchula		4.7	19.8	22.2	20.5	15.3		17.5	
Dolkha		1.9	26.2	28.5	16.6	9.4		17.4	0.0
Dolpa			0.3	5.1	12.2	8.2	70.2	3.8	0.1
Humla			2.3	8.9	19.4	58.7		10.7	
Jumla				25.3	49.7	13.9	3.8	7.3	
Kalikot		1.8	20.6	39.4	37.3	0.8			
Manang			0.3	3.7	14.6	13.9	42.1	25.4	
Mugu			5.6	19.3	20.6	17.7	31.2	5.3	0.3
Mustang			0.0	4.0	4.7	2.7	79.8	8.8	
Rasuwa		1.2	11.4	20.8	20.0	11.8	2.0	32.9	0.0
Sankhuwasabha	0.3	10.0	24.8	23.3	12.8	8.4		20.4	
Sindhupalchok		6.0	37.2	24.5	15.1	7.8		9.1	0.4
Solukhumbu		0.7	9.3	20.6	16.6	28.3		24.4	
Taplejung		2.4	14.8	19.5	16.8	38.8		7.7	

Source: TISC Map and Database. Note: The "Water body" only calculates river deltas and some lakes.

6 Agro-Ecological classification in Nepal

In addition to the physiographic classification which was adopted by the Forestry Master Plan (MPFS, 1988) and also used by the Ministry of Agriculture, the agricultural sector has made use of an agroecological classification based on altitude, most notably the Master Plan for Horticulture Development (HDMP, 1990) and The Master Plan for Livestock Development (LSMP, 1993), and also the local research and extension work of the National Agriculture Research Council (NARC) through its research stations (Carson & Sharma, 1992). Other agencies and individuals also attempted to elaborate agroecological classifications (e.g. Nelson, 1980; APROSC, 1990; Lundberg, 1992) as described in Carson & Sharma (1992) and farming systems (e.g. LRMP, 1986; Metz, 1989; Turton *et al.*, 1995; Floyd, 1997).

The Master Plan for Horticulture Development (HDMP, 1990) mapped the country in a series of black and white maps (1:250.000) based on topographic information from the Land Resources Mapping Project showing potential production pockets for a range of fruit trees. The Master Plan for Livestock Development (LSMP, 1993) did not map their potential production areas, however, it made detailed recommendations on the use of fodder and forage species in different agroecological zones.

The master plan for livestock (LSMP, 1993) and the main author of the Land Resources Mapping Project (LRMP, 1986) and the Horticulture Master Plan (Carson & Sharma, 1992) made references to the vegetation mapping carried out by French and Nepalese scientists in the 1970's and 1980's as potentially the best basis for Agro-Ecological classification of Nepal (the same maps that are used as a basis for the Potential Vegetation Map).

The Biodiversity Profile Project (BPP, 1996) used the physiographic classification of Land Resources Mapping Project (LRMP, 1986) for the description of biotic provinces. The 5 Physiographic Zones were merged into 3 Physiographic Zones or distinct biotic provinces[10]: (i) Terai and Siwaliks; (ii) Midhills, and (iii) Highlands (High Himal and High Mountains) and 3 Floristic Zones were used: (i) Western Nepal to the west of 83°28'E, (ii) Eastern Nepal to the east of 86°00'E, (iii) Central Nepal in between the two. For the altitudinal distribution the vegetation classification of Dobremez (1972) was followed.

The Potential Vegetation Map has a different nomenclature for the zones (but follows the same height intervals) as compared to one of the previous agro-ecological classifications (Master Plan for Horticulture Development). The Potential Vegetation Map calls the lowest part of Nepal Tropical and continues upwards to Sub-Tropical, Temperate and Alpine. The agro-ecological classifications start from Tropical and continues upward to Sub-Tropical, Warm and Cool Temperate. See table 12 for a comparison, and above for a justification for selecting tropical as the lowest part.

[10] As discussed above the physiographic zones are not distinct, but overlapping.

Table 12. Comparison of Zone nomenclature of Ecological classifications in Nepal[11]

Altitude range (m)	Potential Vegetation Map	MP Horticulture	MP Livestock	BPP
0-300	Lower Tropical	Tropical	Tropical	Tropical
300-1000	Upper Tropical	Tropical	Tropical	Tropical
1000-1500	Subtropical	Subtropical	Subtropical	Subtropical & Temperate
1500-2000	Subtropical	Warm Temperate	Subtropical	Subtropical & Temperate
2-3000	Temperate	Cool Temperate	Temperate	Subtropical & Temperate
3-4000	Sub-Alpine	Sub-Alpine	Sub-Alpine	Sub-alpine & Alpine
4-5000	Alpine	-	Alpine	Sub-alpine & Alpine
Above 3000	Trans-Himalayan	-	Steppe	-

Sources: HDMP (1990); LSMP (1993); BPP (1996); and present document

[11] Nepal Biodiversity Action Plan (NBAP (Draft), 2000) mainly uses the physiographic classification but frequently refers to the vegetation type classification by Dobremez and to BPP.

7 A tool for implementation of the Forest Sector Policy; the Agricultural Perspective Plan, and the Biodiversity Action Plan

As shown in the preceding chapters the Potential Vegetation Map is the best descriptor to date of the landscapes in Nepal and incorporates both the potential natural vegetation and the potential for human use. In the following the potential of the Potential Vegetation Map to support forestry, agriculture and biodiversity will briefly be discussed and draft maps will be presented.

7.1 Agro-ecological zonation and forestry

Presently the forestry sector in Nepal (as in most other countries) is undergoing a change from emphasis on traditional forestry (plantation forestry and commercial extraction from natural forests) towards community forestry. It is expected that the majority of the forests in the Mid-Hills in Nepal (and a sizeable fraction of the Tarai forests) will be handed over to local Forest User Groups (FUGs), (HMG, 2000), and managed by the FUGs in accordance with approved Operational Plans. The single biggest issue in forestry in the future will therefore be FUG management of the forests.

The Forest Sector Policy document (HMG, 2000) outlines six primary development programmes of the Forest Sector Master Plan.

- community and private forestry
- national and leasehold forestry
- development of medicinal and aromatic plants and non-wood products
- development of wood-based industries
- soil conservation and watershed management
- conservation of ecosystems and biodiversity

In addition to the above development programmes the Forest Sector Policy document (HMG, 2000) also includes a strategy to design an integrated forage development programme and development of farming systems.

One of the most important aspects in the development of FUG-silviculture under the community forestry programme is how to include the full range of forest potential and biodiversity in silvicultural prescriptions. Species composition of the forests changes along with altitude, from east to west (latitude) in the country, and with slope aspect of the mountains and hills. The production of the forest and the products that can be extracted from the forests depend on the species composition of the forest, therefore silvicultural prescriptions will depend on the species composition or forest type.

Map 6 provides a broad overview of the distribution of Forest User Groups in the Nepal and map 7 gives an impression of the fragmentation of Lower Tropical Sal and Mixed Hardwood Forest.

Participatory natural forestry management by local communities can be expected to utilise a larger number of species for a range of uses than commercial forestry and most often timber will not be the primary objective of the forest management. Even the use of commercial timber species will be more diversified than in commercial forestry, e.g. the use of sal (Shorea robusta) by local communities is for construction, bedding, leaf plates and poles as support for vegetables rather than for timber alone. Correspondingly more information is required about growth of individual species and manipulation of the species composition by silvicultural prescriptions.

The Leasehold Forestry programme is handing over degraded forestland to the poor and assisting them in re-vegetating the land with useful species of trees, fodder, forage, fruit trees, and agricultural crops. An agro-ecological zonation would be useful to make a proper planning for site matching.

Maps of species distributions would be an important planning tool for development of Wood Based Industries - in conjunction with updated resource information. For example for resin production from Chir pine (Pinus roxburghii), a map of Chir pine distribution and access roads could help planning for a network of production sites for refinement of the resin.

Maps of forest types and species distributions would be an important aspect of Soil Conservation and Watershed Management both for agricultural, horticultural and forestry crops. Moreover if the map is rendered in 3-D, the map could be an interactive tool for planning.

A prerequisite for Ecosystem and Biodiversity conservation is knowledge of species distributions both - actual and potential.

Maps of potential growing zones for forage and fodder would be an important aspect of a strategy to design an integrated forage development programme and development of farming systems.

7.1.1 Development of medicinal and aromatic plants and non-wood products

Development of medicinal and aromatic plants and non-wood products is one of the programmes of the Forestry Sector Master Plan (HMG, 2000). The potential distributions of these species - many of which are herbs occurring in high altitude vegetation are not well known.

Identification of the distributions of the medicinal and aromatic plants within vegetation types would provide important information on the geographical distribution of collection and the cultivation potential. The distributions by ecological zones for a range of species are shown in table 13 and for two species in Map 8.

Table 13. Tentative potential distribution of some medicinal and aromatic plants by Ecological Zones

Ecological Zones	Medicinal Plants
Alpine	*Allium wallichii, Dactylorhiza hatagirea, Ephedra gerardiana, Fritillaria cirrhosa, Hippophae tibetana, Picrorhiza scrophulariiflora, Rheum australe, Rhododendron anthopogon, Swertia multicaulis, Nardostachys grandiflora*
Trans-Himalayan	*Ephedra gerardiana, Hippophae tibetana, Nardostachys grandiflora, Picrorhiza scrophulariiflora, Rhododendron anthopogon, Nardostachys grandiflora*
Sub-alpine	*Astilbe rivularis, Ephedra gerardiana, Fritillaria cirrhosa, Juniperus communis, Juniperus recurva, Picrorhiza scrophulariiflora, Podophyllum hexandrum, Rheum webbianum, Rhododendron anthopogon, Taxus wallichiana, Nardostachys grandiflora*
Temperate	*Artemisia indica, Betula utilis, Cinnamomum tamala, Ephedra gerardiana, Gaultheria fragrantissima, Juglans regia, Juniperus communis, Lilium nepalense, Maharanga emodi, Mahonia napaulensis, Myrica esculenta, Panax pseudo-ginseng, Paris polyphylla, Podophyllum hexandrum, Punica granatum, Rheum webbianum, Rhododendron anthopogon, Rubia manjith, Swertia angustifolia, Taxus wallichiana, Valeriana hardwickii, Valeriana jatamansii, Zanthoxylum armatum*
Sub-tropical	*Alstonia scholaris, Cassia mimosoides, Dichroa febrifuga, Mahonia napaulensis, Myrica esculenta, Phyllanthus emblica, Punica granatum, Syzgium cumini, Terminalia chebula, Woodfordia fruticosa, Zanthoxylum armatum*
Tropical	*Acacia catechu, Aegle marmelos, Boerhavia diffusa, Bombax ceiba, Holarrhena pubescens, Mallotus philippensis, Phyllanthus emblica, Terminalia bellirica, Terminalia chebula, Asparagus racemosus*

Source: T.B. Shrestha (2000)

7.2 Agro-ecological zonation and agriculture/horticulture/ livestock feed

Agricultural, forestry and natural resource development research should be tied to research and extension domains covering the whole country. The present agro-ecological classification system provides a framework for such an extension approach. With knowledge of the individual crop/commodity's ecological limits the potential growing zone can be identified and this will lead to a more efficient allocation of development resources. For example the 'Mountain Districts' of Solukhumbu, Sankhuwasabha and Taplejung has only parts of their cultivated area in cold High Mountain (see table 11), but due to their classification as 'Mountain Districts' the potential for crops that require warmer climates may be ignored (Carson, 1992a). Likewise the potential zone for apples, which is a temperate crop with a requirement for a minimum cold period, but intolerant of high humidity, may be mapped by combining the information from the ecological zone map with the climatic map.

The results from the Master Plan for Horticulture and Master Plan for Livestock can be directly integrated into the Ecological Zone map and can be further detailed for individual crops, including agricultural crops.

The Agriculture Perspective Plan (APP) has a 'Prioritised Production Package' of 7 components (APP, 1995). The objective of the package in the Tarai is to increase agricultural production through irrigation and integrating the area into national and world markets. The objective of the package in the hills and mountains is to increase the production of livestock products and high-value crops.

Agriculture Perspective Plan (APP) Prioritised Production Package of 7 components. (APP, 1995)

- Accelerated agricultural growth
- Large concentrated investment in a small number of input priorities
- Input priorities:
    - Shallow tube well irrigation in the Tarai
    - Agricultural roads
    - Fertilizer
    - Technology system of research and extension
- Small number of high value commodity priorities to facilitate intensification of agriculture, especially in the hills
- High value priorities:
    - Citrus
    - Vegetables and vegetable seeds
    - Apples
    - Apiculture
    - Sericulture
- Strong multipliers from increased farm incomes
- An implementation mechanism that operates at the district and national levels

The APP strategy is based on the assumption that accelerated technological change is the means to increase agricultural production and incomes and the APP strategy states that the priorities within the research and extension programmes need to be fine-tuned to the diverse production conditions and categories of land utilisation in the country. APP (1995) suggests that one of the key issues for the research system is the extent to which Nepal can transfer research results from India and international agricultural research centres. (This was also suggested by the Livestock Sector Master Plan (LSMP, 1993)).

The most important tool for transfer of research results from one area to another is a comparison of climates (and soils). As the Master Plans for Horticulture and Livestock point out, an essential part of a technology system of research and extension would be mapping of research and extension domains based on potential growing zones and mapping of the crop varieties and their ecological limits. The Potential Vegetation Map is a very suitable tool for this.

The APP strategy rests on the (physiographic) assumption that Tarai and Hills are very different. This is of course relevant especially in terms of transport and markets, but as can be seen in tables 10, 11, and 12, and maps 2 and 5, the physiographic classification of Nepal ignores considerable variation in growing conditions for agricultural crops and therefore does not show the full potential for crop production in Nepal. An Agro-Ecological classification through use of the Potential Vegetation Map would be an essential planning tool for the implementation of APP.

Some examples of the potential of the Potential Vegetation Map as a planning tool for implementation of APP are shown below. The maps should be considered as work in progress as changes and improvements are expected. Examples for crops are: Map 9, the potential distribution of rice (two crops, one crop and cold tolerant rice). Map 10, the potential distribution of potato (spring potato, summer potato, and winter potato). Map 11, apple and citrus. Map 12, forage species.

7.3 Brief description of the potential options for each Agro-Ecological Zone

Tentative legends for agro-ecological zone maps have been prepared based on the 36 vegetation types (IUCN, 2000). The legends are only tentative and will be detailed by appropriate experts on each crop type using the climate information from Nayaju & Lillesø (2000) and the ecological information from Shrestha *et al.* (2002).

The tentatively described potential options for each of the Ecological Zones/ Agro-Ecological Zones are presented here - food crops, vegetable crops, fruits, cash crops, non timber forest products (and aromatic plants) as well as livestock/pastures/fodder/forage.

- In the Nival Zone there is no potential agriculture.
- In the Alpine Zone Bhyaglung sheep, Yak/Nak, Chyangra and alpine pasture coexist. These livestock species have a very important role in the economy of the mountain people. Some of the most important medicinal plants in Nepal are collected from this zone.
- In the Sub Alpine Zone crop cultivation is very limited. Naked barley, potato, apple, wild vegetables, cabbage, cauliflower, vegetable seed, amaranthus and buckwheat are normally grown in summer season. The livestock Yak/ Nak, Chauri, Chyangra goat and Bhyaglung sheep are reared. Some of the most important medicinal plants in Nepal are collected from this zone.
- In the Temperate Zone crop cultivation is practiced in both summer and winter season. A range of crop species like cold tolerant rice, summer maize, wheat, barley, potato, apple, walnut, peach, cole crops, off-season vegetables, amaranthus and buckwheat are grown. The livestock species, Chaiuri, Sinhal goat, Baruwal sheep, Hill cattle, Hill buffalo, Chyangra and Angora rabbits are reared.
- In the Sub Tropical Zone rice, spring/summer maize, millet, wheat, potato, stone fruits, citrus/peach, subtropical vegetables, summer/off season vegetables and hill cash crops are cultivated. The livestock, Hill cattle, Hill buffalo, Hill goats, Kage sheep, Black pigs, chickens and Angora rabbits are reared.

In the Tropical Zone double rice, winter, summer and spring maize, wheat, potato, mango, lichi, jack fruit, citrus, wild vegetables, off-season vegetables, tropical vegetable seed, cash crop are cultivated. Intensive agriculture is practiced in this zone and is known as granary of Nepal. The livestock Tarai cattle, Tarai buffalo, Tarai goats, Lampuchhre sheep, Black pigs and chickens are reared.

The diversity of agro-ecological zones permits temperate crops to be grown in winter season of the tropical zones and tropical crops to be grown in summer season of Temperate and Sub Alpine Zone. Spring, summer, autumn and winter seasons are utilised for specific crop production that favour off-season vegetables production depending upon market demand.

7.4 Agro-ecological zonation and Nepal Biodiversity Action Plan

Biodiversity conservation has high priority in the Forest Sector Policy (HMG, 2000) and a landscape planning approach in managing biological diversity on an ecosystem basis will be utilised. A National Biodiversity Action Plan will be adopted to provide an operational planning framework.

The Potential Vegetation Map attempts to show the broad patterns in the landscapes of Nepal as determined by altitude and biogeography (east-west patterns). At this scale it is possible to predict the potential distribution of species and this can be used to describe and identify habitat types and their potential extension within and outside the boundaries of protected areas, and to analyse the distribution of habitats inside the protected areas.

A landscape planning that allows corridors and landscape patterns that promote connectivity for species, communities and ecological processes are regarded as key elements in nature conservation (Bennett, 1999; Lacher,1998a). In order to develop a landscape perspective and to plan for its application the Potential Vegetation Map would be an invaluable tool, and can be directly applied in gap analysis and in identifying critical habitats for flora and fauna (Lacher, 1998b).

The ecology of animals, especially birds, has been more intensively studied in the Andes Mountains in South America (Kattan & Alvarez-Lopez, 1996) as compared to Himalayan birds. Many Andean birds (resident and transitory) have a seasonal migration up and down the altitudinal gradients. It is quite possible that in Nepal the resident birds have similar seasonal altitudinal (vegetation type) preferences.

An example of the potential distribution of four birds is shown in Map 13 and table 14. An example of one fodder tree species is shown in Map 14 (the maps are preliminary).

Table 14. Examples of Potential Vegetation Types for 4 bird species

Name of the Bird	Ecological Zone	Vegetation Type	Habitat Requirement	Food
Great Hornbill (Buceros bicornis)	Tropical	Lower Tropical Sal and Mixed Broad-leaved Forest	Mature forest	Ficus fruits, nut, eggs small mammals, reptiles nesting birds
Pale Blue Flycatcher (Muscicarpa unicolor)	Sub-tropical	Schima Castanopsis Forest	Dense forest, humid secondary forest, bamboo forest on steep hill sides	Insects
Red-headed Bullfinch (Pyrrhula erythrocephala)	Upper Temperate	Mountain Oak Rhododendron Forest	Low bushes, broadleaf, rhododendron oak, conifer forest	Seeds of birch, willow catkin leaf bud, berries, nectar of rhododendron
Desert Wheatear (Oenanthe deserti)	Alpine	Trans Himalayan High Alpine	Arid semi desert tracks, either sandy or rocky scanty shrub	Insects, beetles

Source: H.S. Nepali (data submitted to TISC, 2000). Note: A more complete analysis may show a slightly broader potential distribution.

It would be of great value if the seasonal habitat requirements (within vegetation types) could be identified for the animals and birds that inhabit Nepal. Without this knowledge of use of vegetation by animals and birds on a landscape level, it will be difficult to seriously discuss biodiversity of animals and birds inside and outside parks. This issue is of great importance to community forestry, as the impact of forest changes (resulting from the community forestry programme) will have a (until know) largely unknown effect on animals and birds.

7.4.1 The vegetation types of Nepal and protected areas

Nepal's protected area networks contain a wide range of habitats from tropical savannahs to alpine grasslands and a large number of vegetation types. 16 protected areas are being managed for biodiversity conservation (see Map 15). They are known for their wildlife species but their habitat diversity and ecological dynamics are not adequately documented.

36 major vegetation types are classified and described in the Potential Vegetation Map (see table 15). A preliminary list of species has been assigned to each of the vegetation types. The species lists should be considered preliminary, because there are insufficient studies available to provide final lists[12]. Some vegetation types have been the subjects of very intense studies by botanists (e.g. East Himalayan Oak-Laurel Forest covering 1.6% of the surface of Nepal); other vegetation types have not been systematically studied by botanists (e.g. Lower Tropical Sal and Mixed Broad Leaved Forest covering 17.9% of the surface of Nepal).

The knowledge of the vertical distributions of individual plant species in Nepal is rudimentary at best; the standard reference work for plants, Enumeration of Plants in Nepal (Hara *et al.* 1978, 1979, 1982) contains very sketchy distributions. Especially for one of the most important group of plants in Nepal - the fodder trees - the available information is clearly insufficient. This is most likely due to the fact that these species have become very rare in the natural forest and mostly survive in the farmers' land (Lillesø *et al.*, 2001b) (however, see Map 14 for an example of the potential distribution of a species of this group).

The vegetation types are not equally represented in the protected area system as can be seen from table 15 and a few vegetation types are totally outside.

[12] The species database can be updated through 'rapid vegetation analysis'. Lower and Upper tropical Zones should have high priority

Table 15. Mapped vegetation types in Nepal; tentative species lists; % of Nepal; and % inside/outside protected areas

Ecological Zones	Vegetation Type	Tentative species list	% of Nepal's area	% of vegetation type inside PA
Lower Tropical	Lower Tropical Sal and Mixed Broad Leaved Forest	300	17.9%	7%
Upper Tropical	Hill Sal Forest	187	17.7%	5%
Sub-tropical	Chir Pine Forest	87	5.0%	1%
	Chir Pine-Broad Leaved Forest	41	8.9%	1%
	Eugenia-Ostodes Forest	39	0.0%	0%
	Schima-Castanopsis Forest	343	8.3%	7%
Temperate	Cedar Forest	18	0.1%	2%
	Cypress Forest	40	0.1%	34%
	Deciduous Maple-Magnolia-Sorbus Forest	13	0.1%	100%
	Deciduous Walnut-Maple-Alder Forest	48	0.1%	3%
	East Himalayan Oak-Laurel Forest	296	1.6%	25%
	Lithocarpus Forest	174	0.0%	0%
	Lower Temperate Oak Forest	140	4.4%	5%
	Mixed Blue Pine-Oak Forest	126	0.4%	9%
	Mixed Rhododendron-Maple Forest	57	0.4%	18%
	Mountain Oak-Rhododendron Forest	34	0.3%	10%
	Olea Forest	12	0.0%	0%
	Rhododendron Forest	110	0.1%	0%
	Spruce Forest	105	0.7%	5%
	Temperate Juniper Forest	47	0.0%	92%
	Temperate Mountain Oak Forest	197	2.8%	17%
	Upper Temperate Blue Pine Forest	94	0.7%	16%
	West Himalayan Fir-Hemlock-Oak Forest	82	0.2%	13%
Sub-alpine	Birch-Rhododendron Forest	188	3.8%	26%
	Fir Forest	188	3.7%	26%
	Fir-Blue Pine Forest	12	0.1%	70%
	Fir-Hemlock-Oak Forest	49	0.4%	0%
	Fir-Oak-Rhododendron Forest	100	0.1%	24%
	Larch Forest	66	0.1%	95%
	Sub-alpine Mountain Oak Forest	45	0.7%	1%
Alpine	Dry Alpine Scrubs	75	0.2%	83%
	Moist Alpine Scrubs	142	3.4%	35%
	Upper Alpine Meadows	259	4.2%	34%
Trans-Himalayan	Trans-Himalayan High Alpine Vegetation	49	5.8%	60%
	Trans-Himalayan Lower Caragana Steppe	50	0.3%	97%
	Trans-Himalayan Upper Caragana Steppe	145	1.5%	73%

Source: Shrestha *et al.* (2002)

In addition to the mapped vegetation types a number of riverine forest types (see table 16) and grassland types have been listed and partly described Shrestha *et al*. (2002).

Table 16. A Synopsis of Dominant Riverine Vegetation of Nepal

80°04' E - 83° E	83° E - 85° E	85° E - 88°12' E
Alpine Zone		
Moraine/Screes	Moraine/Screes	Moraine/Screes
Sub-alpine Zone		
Myricaria-Seabuckthorn Birch-Willow-Sorbus	Myricaria-Seabuckthorn-Willow Larch Forest Birch-Willow-Sorbus	Myricaria-Seabuckthorn-Willow Larch Forest Birch-Willow-Sorbus
Temperate		
Deciduous Walnut-Maple-Alder Forest Alder-Poplar Forest Poplar-Seabuckthorn	Maple-Osmanthus-Holly Forest	Deciduous Maple-Magnolia Forest
Sub-tropical		
Alder Forest Olea Forest Alder-Birch Forest	Alder Forest Alder-Birch Forest	Alder Forest Alder-Birch Forest
Tropical		
Upper Tropical Riverine Forest Tropical Deciduous Riverine Forest Riverine Khair-Sissoo Forest	Upper Tropical Riverine Forest Tropical Evergreen Riverine Forest Tropical Deciduous Riverine Forest Riverine Khair-Sissoo Forest	Upper Tropical Riverine Forest Tropical Evergreen Riverine Forest Tropical Deciduous Riverine Forest Riverine Khair-Sissoo Forest

Source: Shrestha *et al*. (2002). Note: These vegetation types have not been mapped, but their potential zones can easily be identified in the field. The 3 sectors along the length of Nepal roughly correspond to the Karnali, the Gandaki, and the Koshi watersheds.

The Potential Vegetation Map would provide an invaluable tool for evaluation of the protection of the flora and fauna in Nepal (this would, however, require more complete knowledge of the distribution of important species of plants and animals).

8 Some considerations for improvement of the Potential Vegetation Map

The Potential Vegetation Map is a digital map with a digital species database. Contrary to what was possible only a few years ago, the revolution in computing power and proliferation of good, inexpensive software has made it possible to update and revise the digital map and database on a regular basis.

8.1 Establishing a multi-sector Board of experts and agreed guidelines for updating the Potential Vegetation Map

A large number of organizations and individuals would benefit from using the Potential Vegetation Map. The use will create new demands for utilities that the map is expected to produce and will also reveal what parts of the map should be fine-tuned.

TISC should therefore initiate discussions with relevant institutions and create a multi-sectoral Board with members from relevant ministries and research institutions. Preliminary suggestions would be representatives from Forests and Soil Conservation, National Parks and Wildlife Conservation, Soil Conservation, Plant Resources, Horticulture, Livestock, and Agriculture, Nepal Agricultural Research Council.

The Board should as its first action create guidelines and quality criteria for the updating. The Board should also be vested with an authority to officially update the map and database and monitor the use.

8.2 Species in vegetation types

It is likely that the number of species in each vegetation type is a reflection of the intensity of research in the forest type rather than the actual number of species potentially available in the vegetation type (see table 15 for the number of species per vegetation type).

The main reference work for the distribution of plants in Nepal, the enumeration of plants in Nepal (Hara et al., 1978, 1979,1982) has incomplete information on the distribution of plants (it was never intended as a reference work for a Potential Vegetation Map). Therefore a continuing work to update the database should be to enrich the vegetation types with more species.

The enrichment has to be done in accordance with strict criteria for the quality of the work carried out. However, in agreement with the current paradigm for classification of vegetation (see 2.1), vegetation types are not likely to be static climax vegetation with fixed vegetation composition (that

can be described by profile diagrams of species composition), but rather vegetation types have species compositions that are influenced by history of the area as well as the physical limits to the species' distributions.

Correspondingly the updating of the species lists by vegetation types should be pragmatic, but with strict criteria for the quality of surveys, the information (species lists) that can be extracted from the surveys will of course never be complete, and the information will be a compromise between completeness of the information and the cost of obtaining the information.

The following considerations and guidelines should be used when accumulating species for the species lists for the vegetation types:

The number of species observed in any small sample of individuals from a vegetation type will never equal the habitat's true species diversity. As sample size increases in area or in number of stems, the cumulative number of species approaches – at a diminishing rate – the total species diversity of the habitat (Stern, 1998).

Rapid ways to survey vegetation are required. Data collected in rapid assessments has been used in many countries for local and regional comparisons of relative species richness and relative abundance at a fraction of the cost and time of traditional plots, where simply setting up the plots can take as much time as quantifying their vegetation (Stern, 1998).

Some useful references on the design and implementation of vegetation surveys are: Condit *et al.* (1998); Hall *et al.* (1998); Kindt and Coe (in prep.); Sheil *et al.* (2002); Sheil *et al.* (2003); Stern (1998).

8.3 Vegetation types

The Potential Vegetation Map is intended as a tool for silviculture, biodiversity, agro-ecology and several other fields. Through the use of the map (and through updating the species lists) it is quite likely that experience will tell that some forest types should be merged or split up or the boundaries should be changed. This will be part of the process of getting a better understanding of the landscape in Nepal.

8.4 The scale of the map

The scale of the Potential Vegetation Map is presently 1:250.000 and it is overlaid on a base-map with 500m height curves (plus one 305m above sea level height curve). During the final preparation of the map in the summer of 2000, it was hoped that the map could be overlaid on a base map with 300 feet height curves (however, the opportunity did not materialize). For agro-ecological classification, the 500m height curves is too coarse for detailed prescriptions, it should therefore be one of the most important tasks for TISC to collaborate with other agencies (especially MENRIS of ICIMOD) to improve the base-map[13].

[13] Presently not all lakes are included in the map, this should also be rectified.

8.5 3-D production

The utility of the map could be considerably improved if it can also be rendered in 3 dimensions. This can easily be done at a reasonable cost of purchasing the appropriate module of ARC-View. This will in particular be useful for landscape analysis of catchment areas, both for agro-ecological classification, biodiversity, silviculture and hydrology.

The idea was already used in Land Resources Mapping Project (LRMP, 1986) as one profile for each of the physiographic regions. With the present GIS system including the 3-D module, an expanded set of utilities and 300 feet height curves, profiles could be produced for a large range of crops, natural vegetation and farming systems for any part of Nepal.

8.6 Expansion of the utilities

A database of all important agricultural, horticultural, fodder and forage crops should be elaborated in collaboration with appropriate experts within the agricultural research system (first and foremost Nepal Agricultural Research Council) using the Horticultural Master Plan methodology for producing quality information and maps.

Nepal has a potential of 700 species of different medicinal and aromatic plants in its flora of 7000 species. A large number of them have market value and are exported on regular basis. A database of the species should be elaborated and their distributions should be determined.

A continuously updated land use layer should be incorporated, especially a forest cover map.

A farming systems layer should be elaborated by updating the information from the Land Resources Mapping Project (LRMP, 1986) and by utilising the research carried out at the agricultural research centers Lumle and Pakhribas and other relevant information.

A soil layer should be elaborated for the entire country to the detail that is possible (sensu Carson and Sharma, 1992).

The road/trail map should be updated so that market access can be estimated.

8.7 Elaborating a key of the Potential Vegetation Map for use in extension

Presently the map is explained academically, it is however, possible to elaborate a description of the map in layman terms that can be used in extension (T.B. Shrestha, personal communication).

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Vegetation Maps of Nepal

Map no. 1 - Ecological Zones with Moisture Regions

Map no. 2 - Ecological Zones with Physiographic Regions

Map no. 3 - Settlement with Ecological Zones and Physiographic Regions

Map no. 4 - Administrative Boundary with Physiographic Regions

Map no. 5 - Ecological Zones of Three Different Districts

Map no. 6 - Forest User Groups (FUGs) with Ecological zones

Map no. 7 - Forest and Shrub Cover in Lower Tropical Zone

Map no. 8 - Potential Distribution of NTFPs and Medicinal Plants/*Asparagus racemosus* and *Nardostachys grandiflora*

Map no. 9 - Potential Distribution of Food Crops/Rice

Map no. 10 - Potential Distribution of Food Crops/Potato

Map no. 11 - Potential Distribution of Fruit Trees/Apple and Citrus

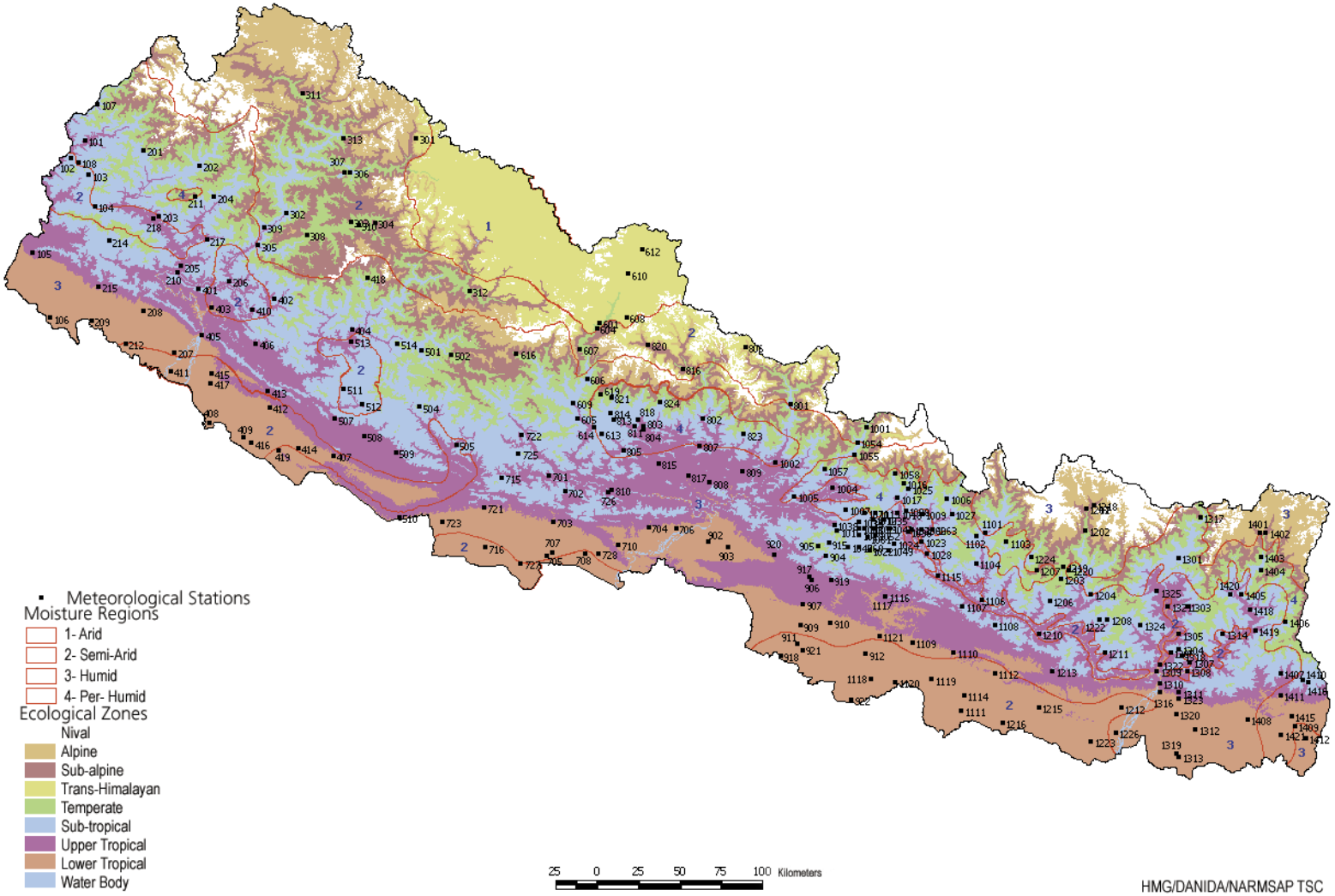
Map no. 12 - Potential Distribution of Forage Species/*Elymus nutans* and *Saccharum spontaneum*

Map no. 13 - Potential Habitats of Four Bird Species

Map no. 14 - Potential Distribution and Planting Sites for *Bauhinia purpurea*

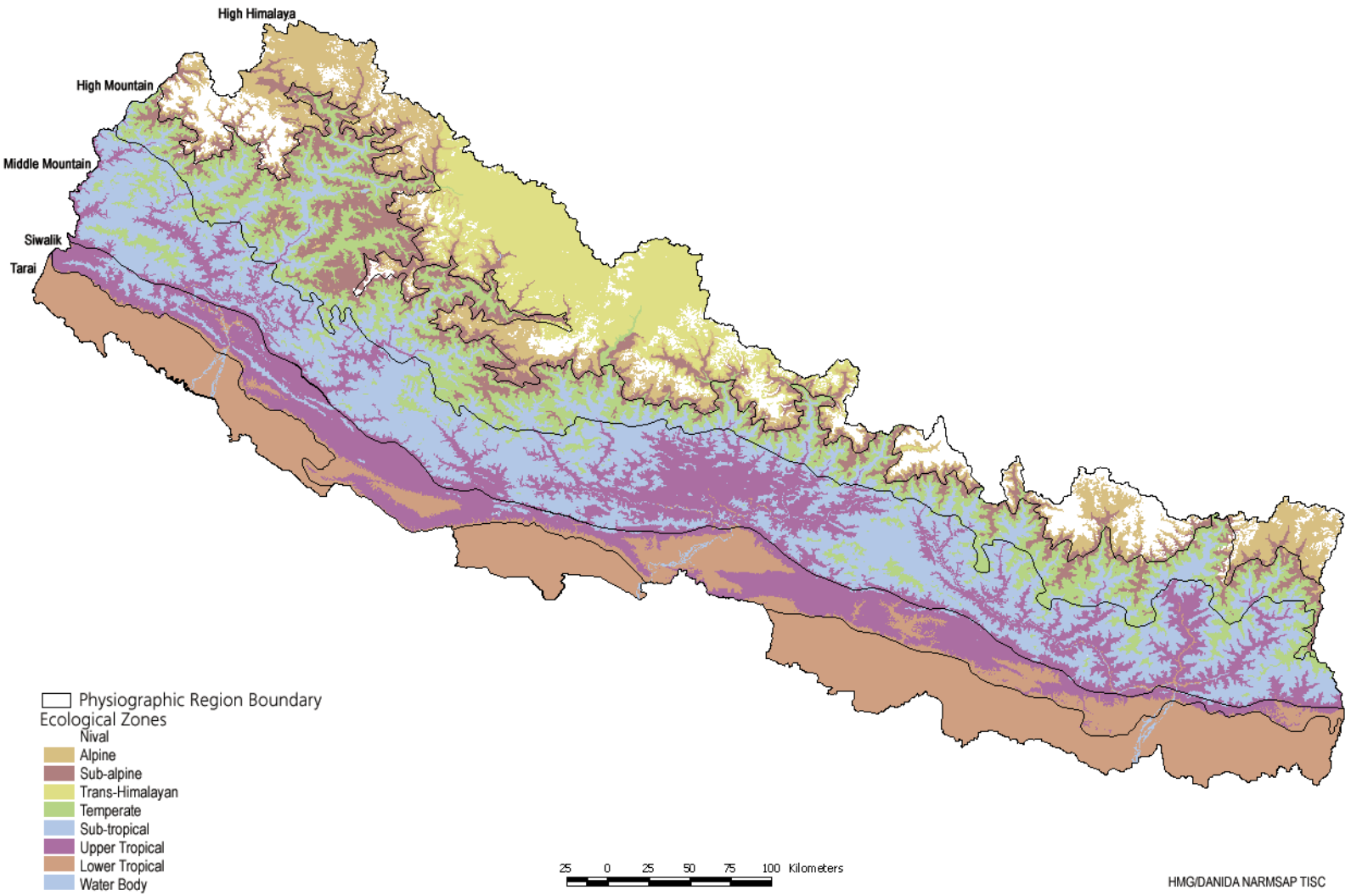
Map no. 15 - Protected Areas with Ecological Zones

Ecological Zones with Moisture Regions



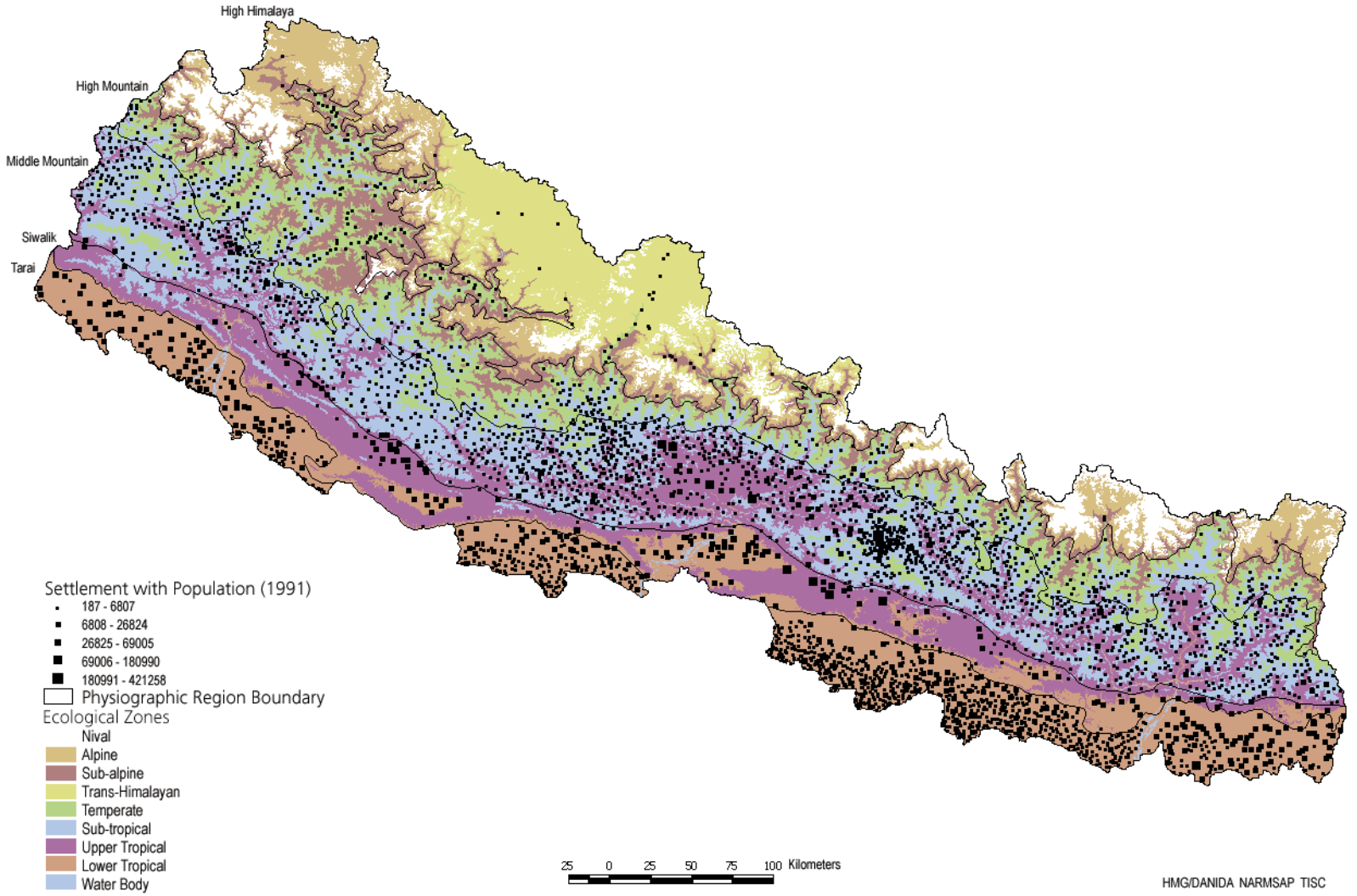
Map 1

Ecological Zones with Physiographic Regions



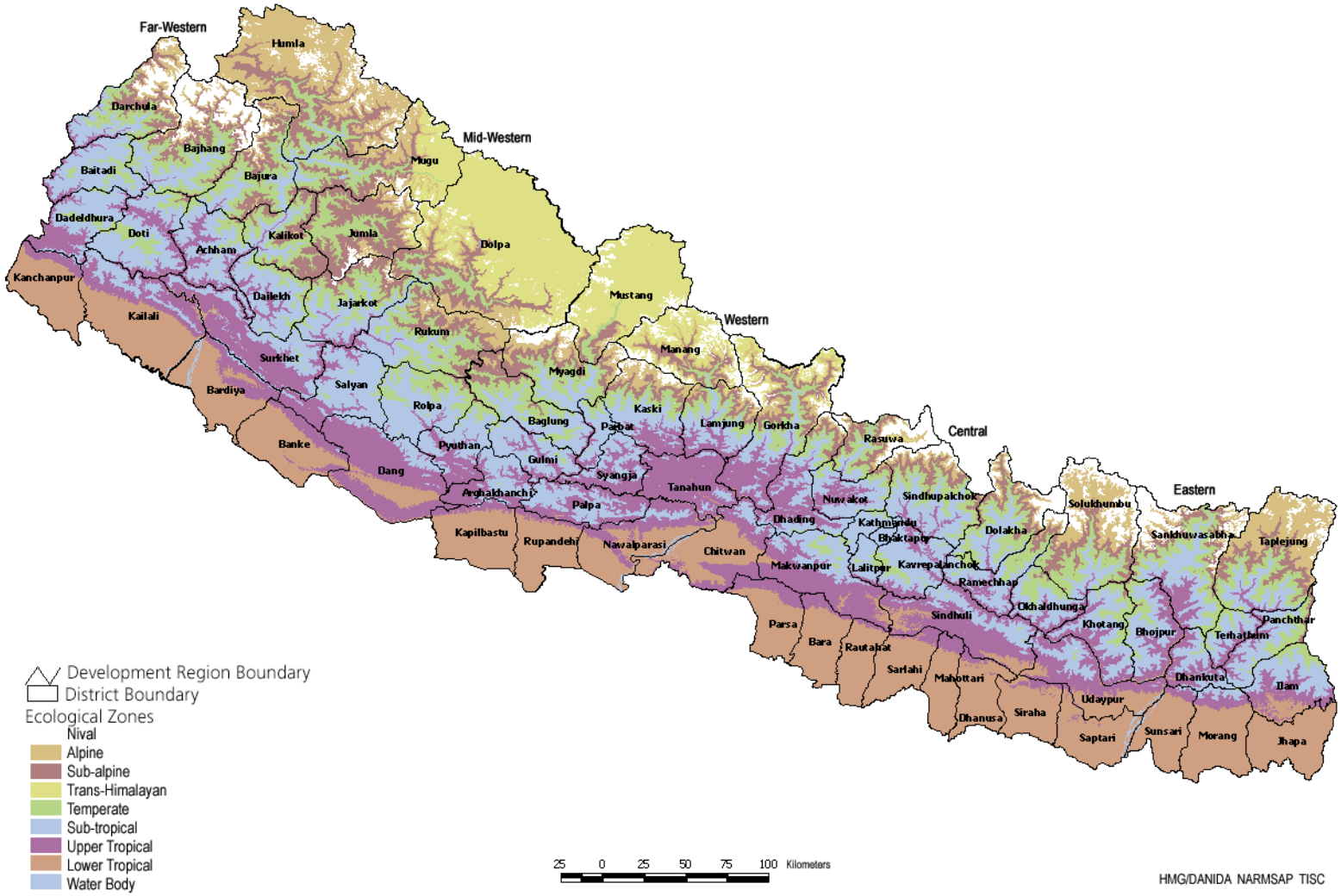
Map 2

Settlement with Ecological Zones and Physiographic Regions



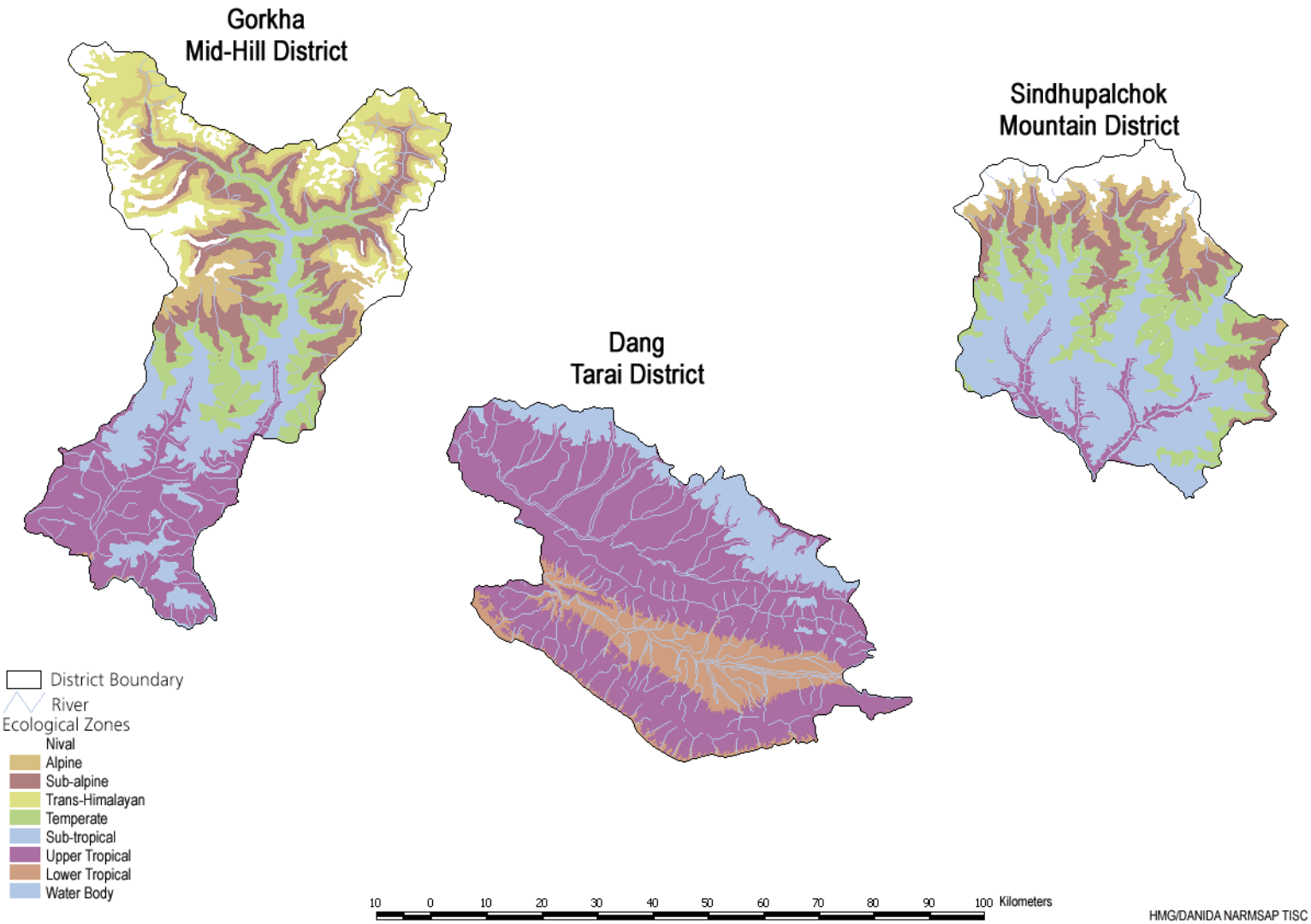
Map 3

Administrative Boundary with Physiographic Regions



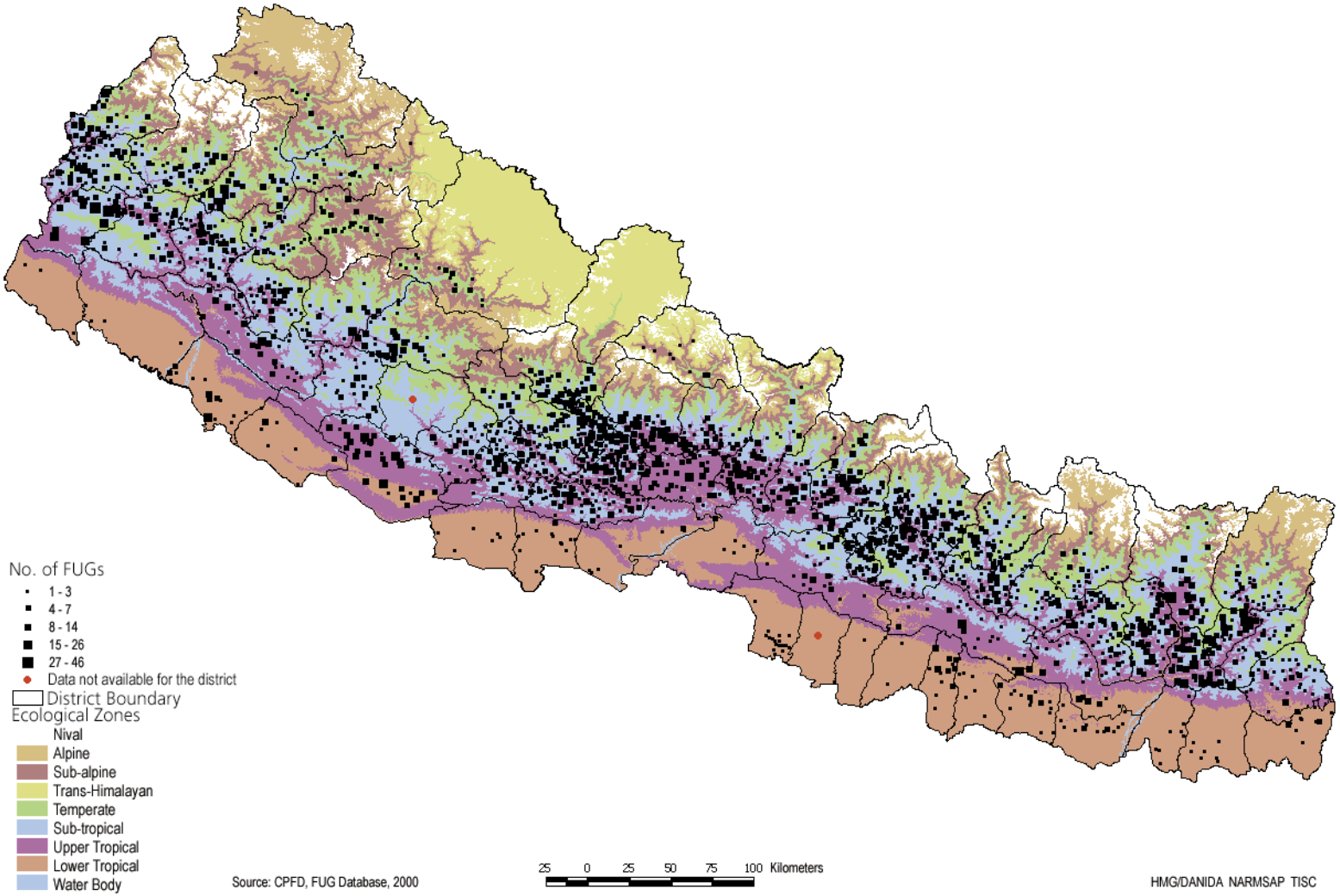
Map 4

Ecological Zones of three Different Districts



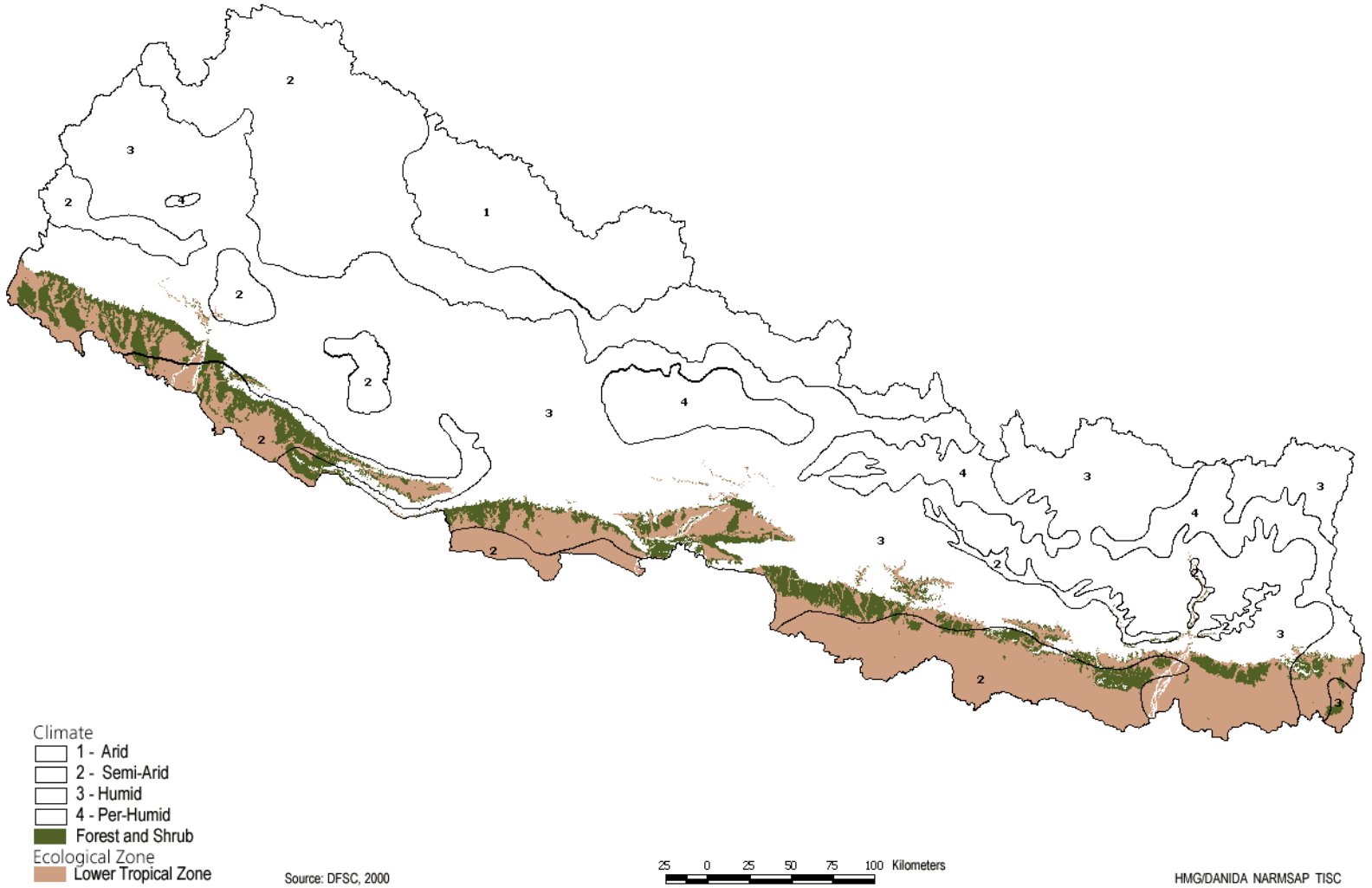
Map 5

Forest User Groups (FUGs) with Ecological Zones



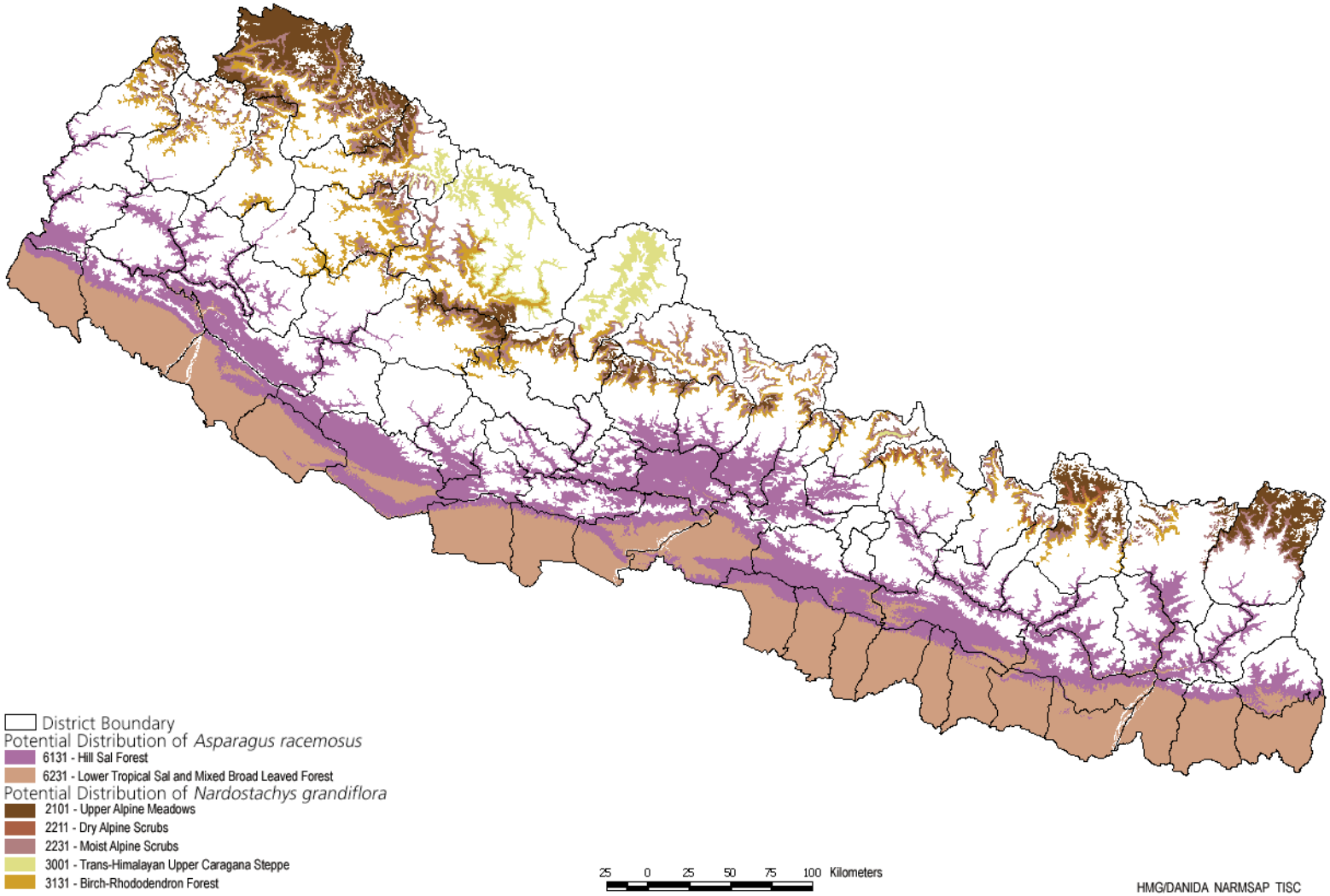
Map 6

Forest and Shrub Cover in Lower Tropical Zone



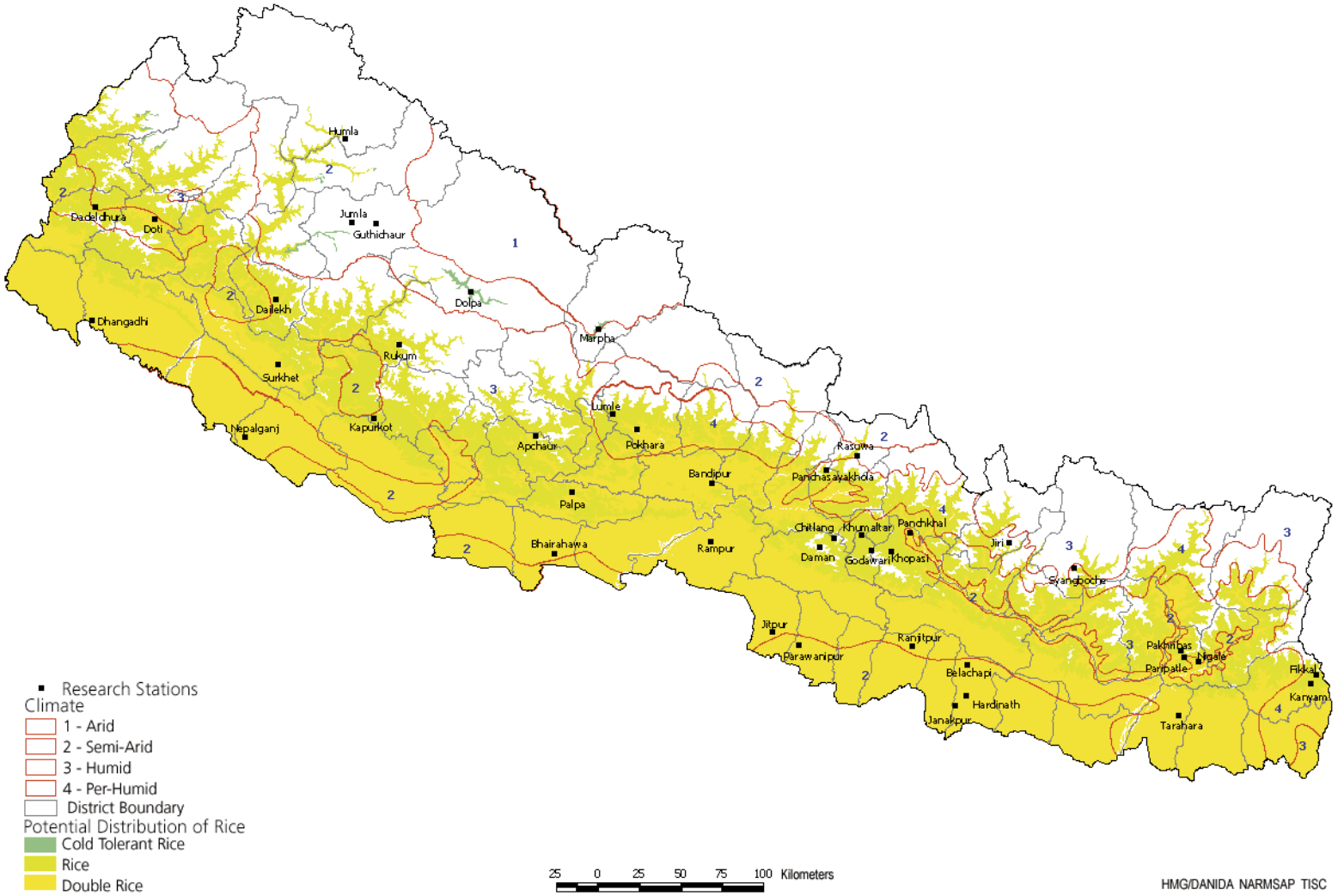
Map 7

Potential Distribution of NTFPs and Medicinal Plants
Asparagus racemosus and *Nardostachys grandiflora*



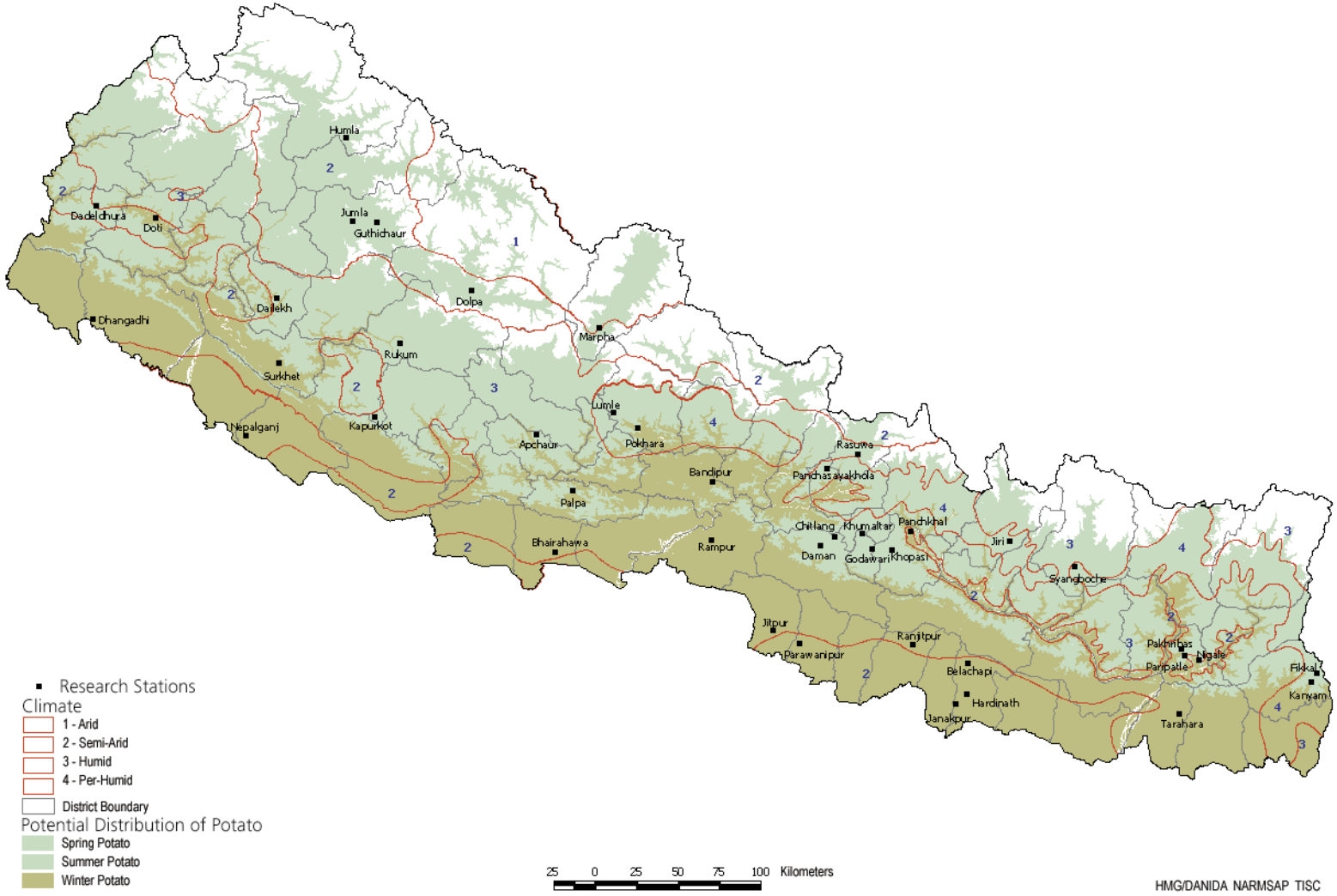
Map 8

Potential Distribution of Food Crops
Rice



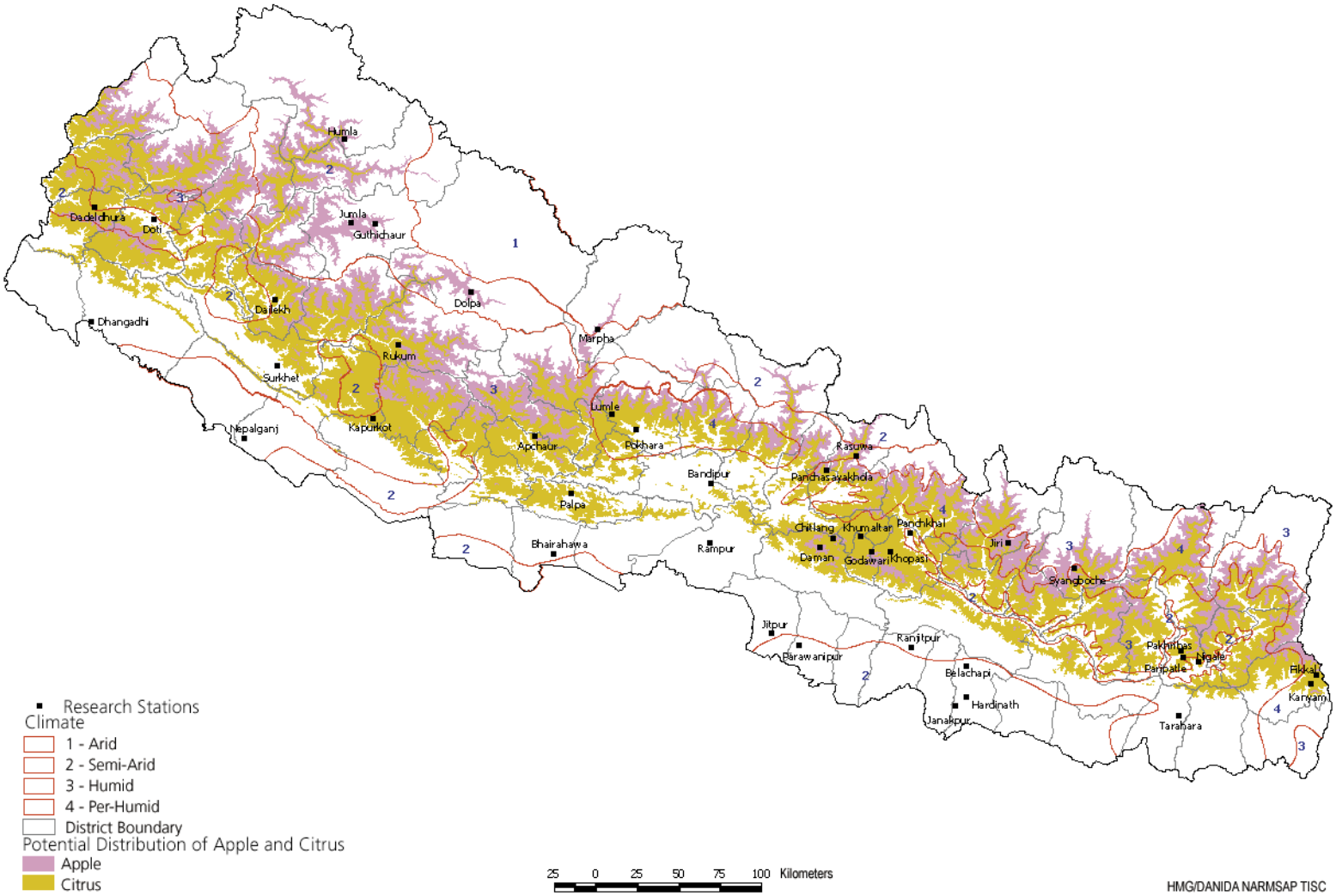
Map 9

Potential Distribution of Food Crops
Potato



Map 10

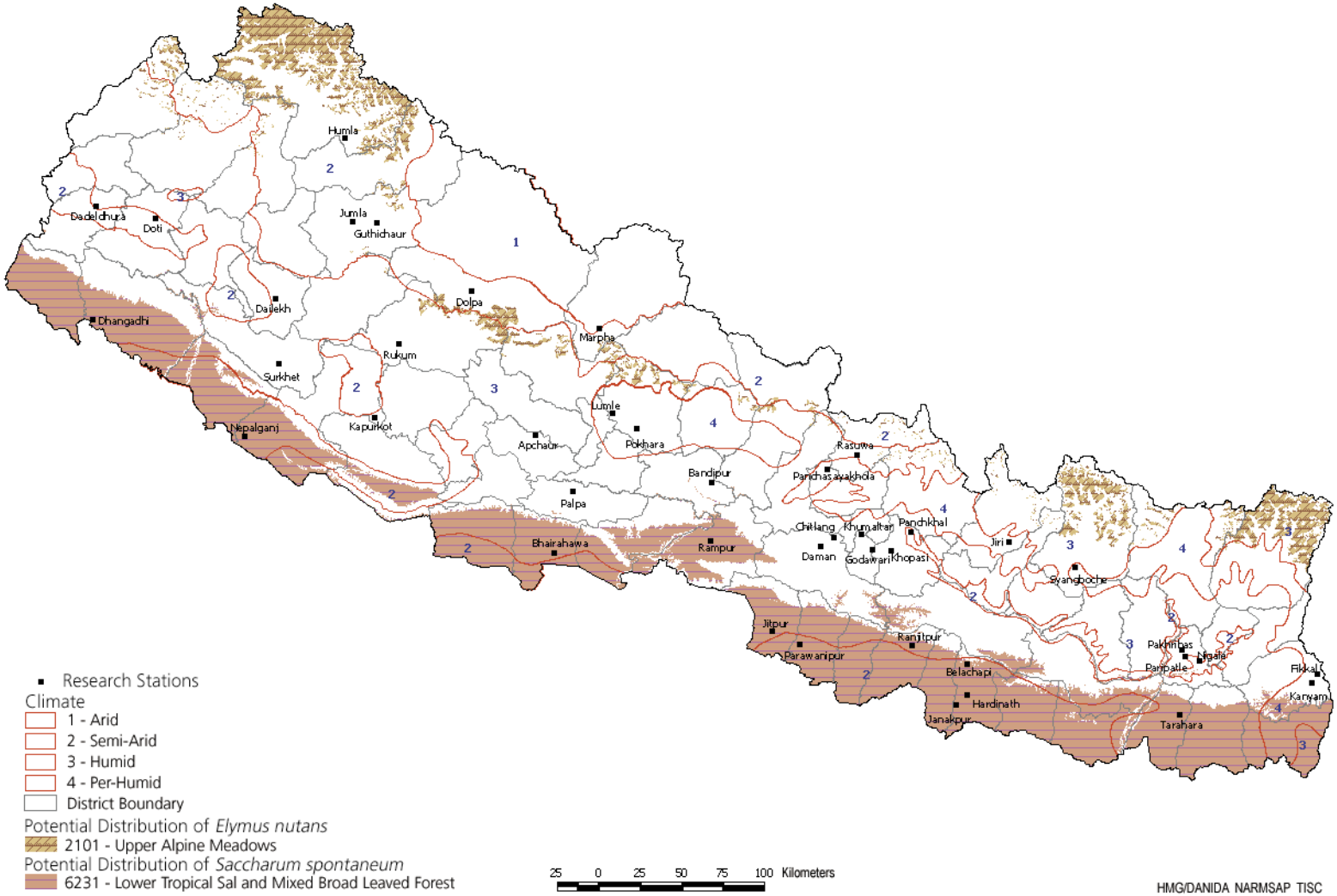
Potential Distribution of Fruit Trees
Apple and Citrus



Map 11

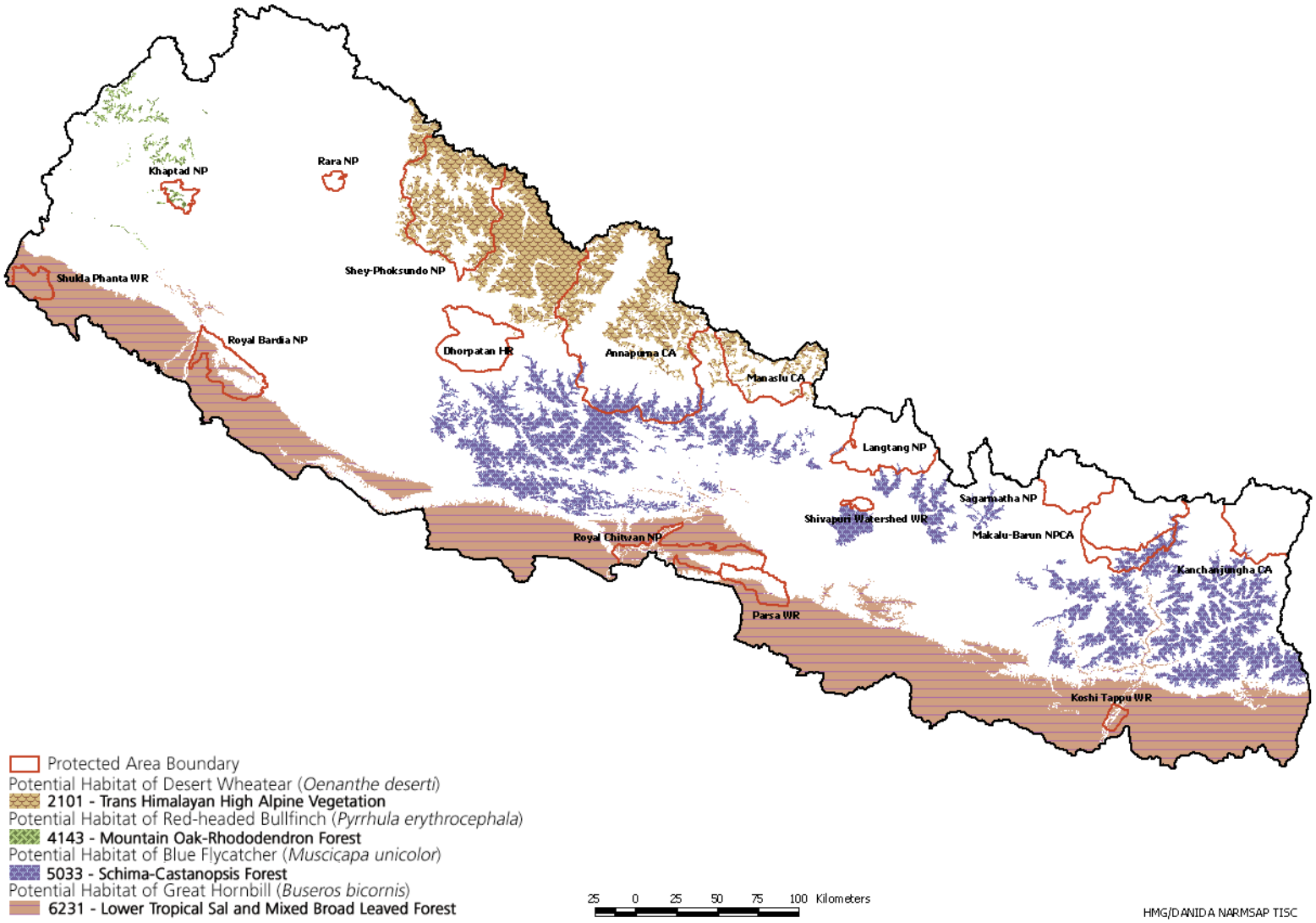
Potential Distribution of Forage Species

Elymus nutans and *Saccharum spontaneum*



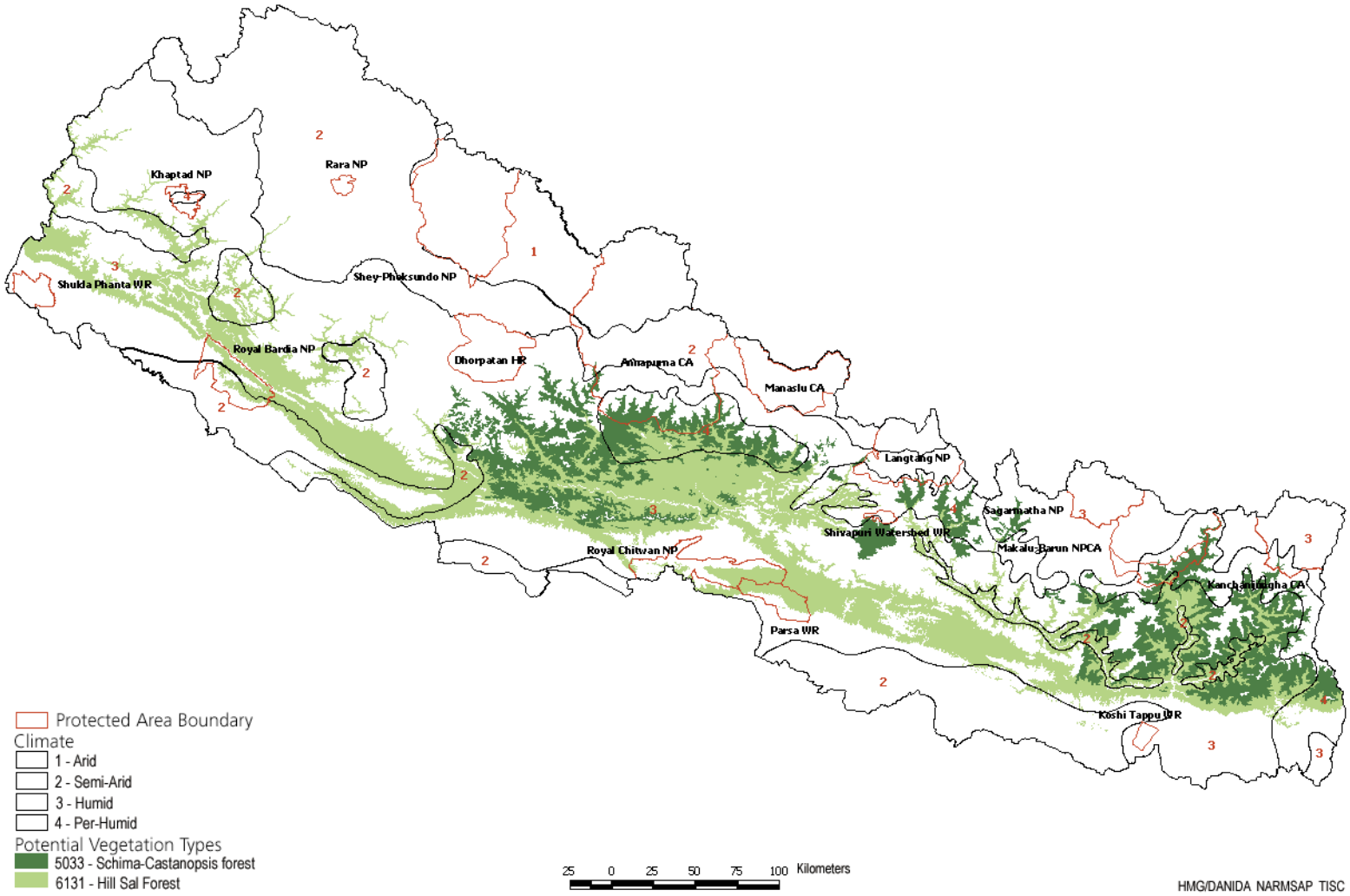
Map 12

Potential Habitats of Four Bird Species



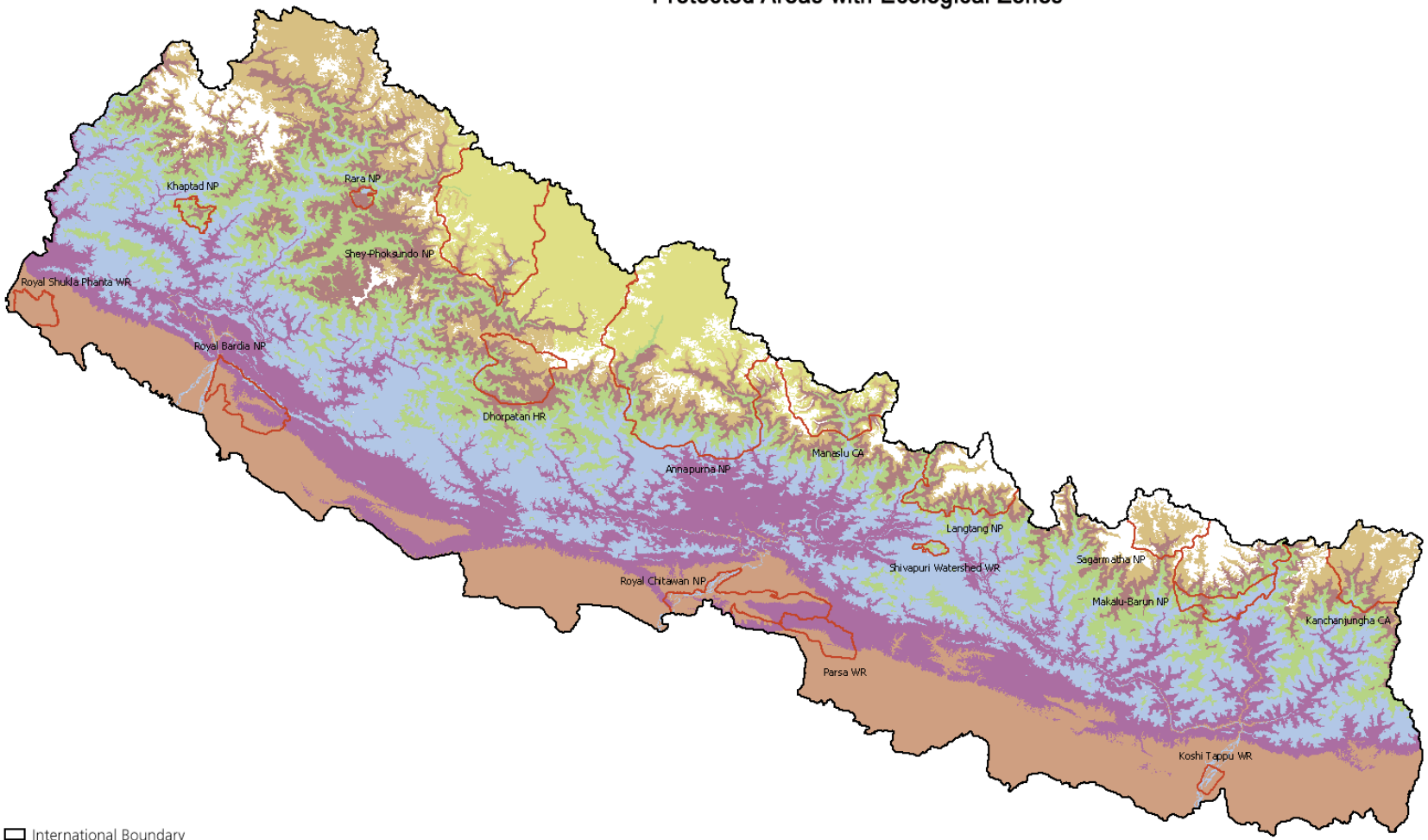
Map 13

Potential Distribution and Planting Sites for
Bauhinia purpurea



Map 14

Protected Areas with Ecological Zones



Map 15