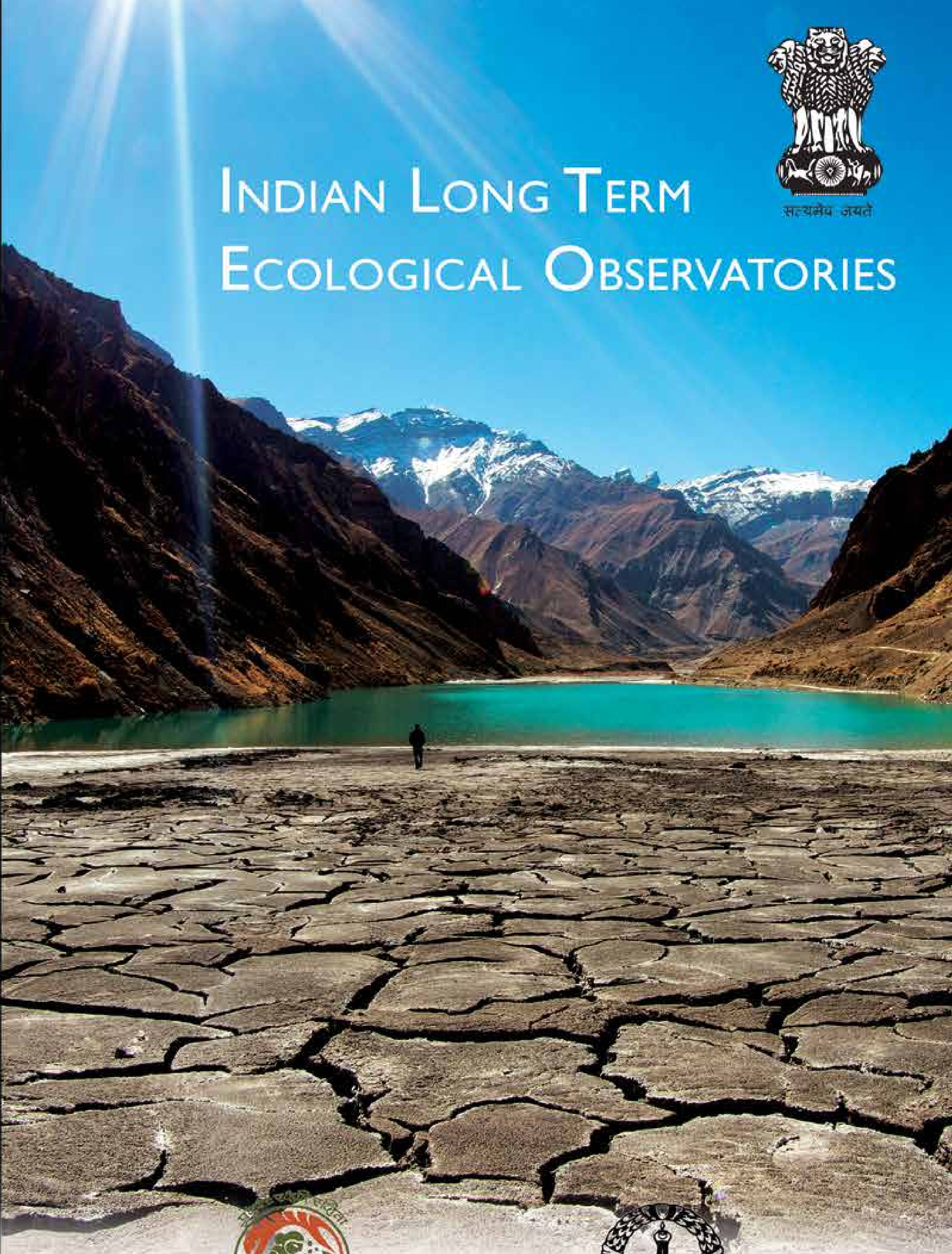
INDIAN LONG TERM ECOLOGICAL OBSERVATORIES



सत्यमेव जयते

Nature Protects if She is Protected

Ministry of Environment, Forest and Climate Change, Government of India

INDIAN INSTITUTE OF SCIENCE

भारतीय विज्ञान संस्थान

Indian Institute of Science, Bangalore

Credits
Prepared for the Ministry of Environment, Forest and Climate Change by J.R. Bhatt and R. Sukumar.

Produced by M. Thaker, S. Bagchi and K. Shanker, with inputs and contributions from J. Krishnaswamy, K. Kunte, N. Namboothri, S. Quader, N. Rai, J. Ratnam, V.V. Robin , M. Sankaran, A. Sridhar, K.A. Subramanian and A.T. Vanak.

Design and layout
Suneha Mohanty and Muralidharan. M

Images, illustration and map
Adhith Swaminathan - (pages 25, 27, 31, 32, 35, 42, 44, 50, front cover)
Abi Tamim Vanak - page 40
Kalyan Varma - (opposite minister's message, pages 4, 6, 9, 10, 22, 23, 24, 28, 30, 32, 33, 36, 37, 38, 39, 41, 43, 47, 48, 52, back cover)
Mahima Jaini - page 46
Prasenjeet Yadav - (contents page, pages 12, 14, 19, 20, 21, 26, 34, 40)
Prabha Mallya - page 16
R. Sukumar - page 45
Vijayakumar S.P. - page 18

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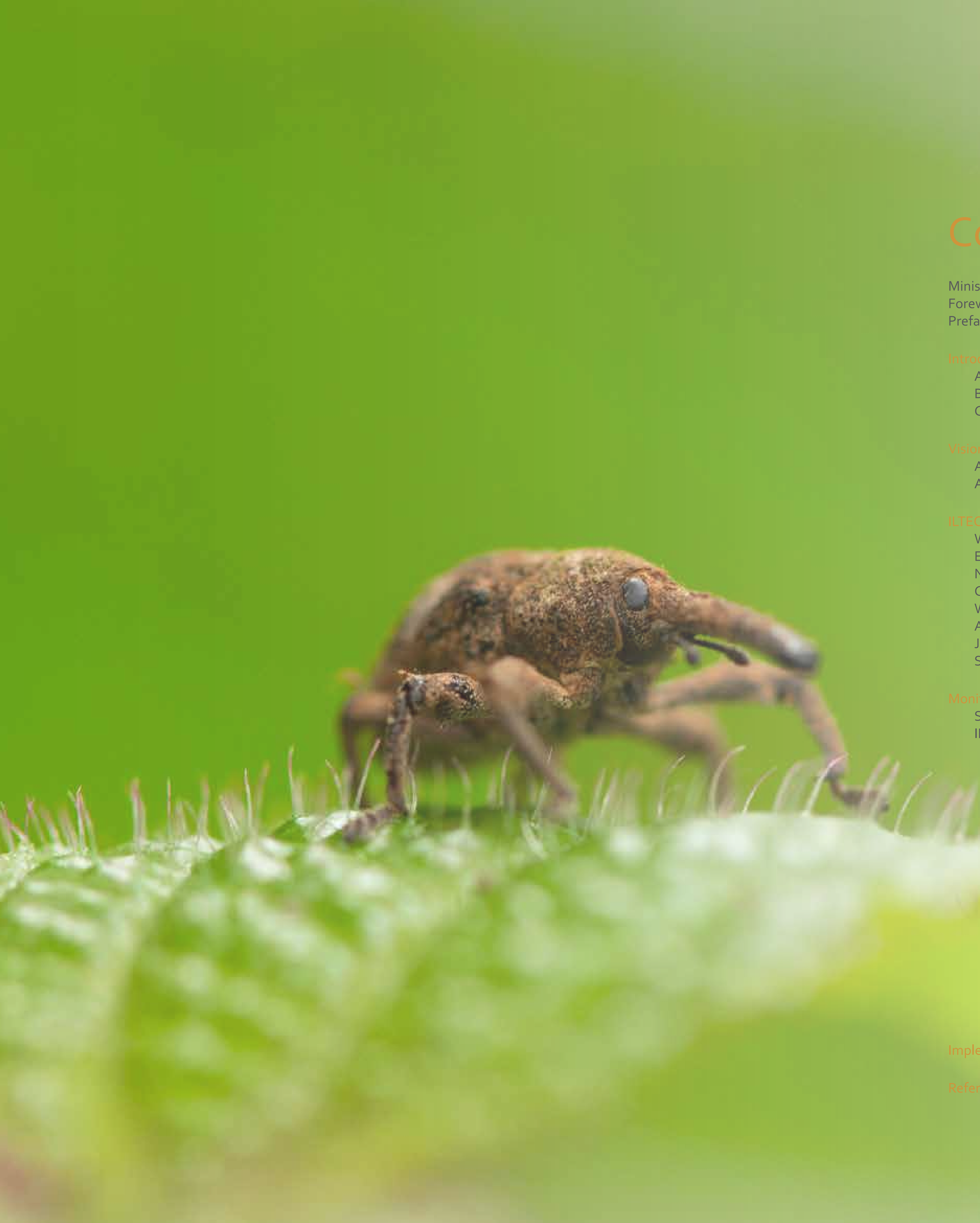

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राज्य मंत्री (स्वतंत्र प्रभार)
MINISTER OF STATE (INDEPENDENT CHARGE)
पर्यावरण, वन एवं जलवायु परिवर्तन
ENVIRONMENT, FOREST & CLIMATE CHANGE
भारत सरकार / GOVERNMENT OF INDIA

MESSAGE

Climate Change was virtually an unknown issue in the 1980s. However, today it has occupied the centrestage. Bulk of the earlier build-up of green house gases (GHG) is on account of developed countries, which are even today the largest sources of gaseous emissions. In spite of this and in a spirit of global cooperation, the developing countries, including India, who have done little or nothing to create the problem are Parties to the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol.

Our voluntary commitments are enshrined in our Intended Nationally Determined Contribution (INDC) to UNFCCC which, inter-alia, embodies reduction of emission intensity of our GDP by 33 to 35 percent by 2030 from 2005 level. The Indian INDC also endeavours to create an additional carbon sink of 2.5 to 3 billion tonnes of CO_2 equivalent through additional forest and tree cover by 2030.

India is also envisaging to better adapt to climate by enhancing investments in development programmes in sectors vulnerable to climate change, particularly agriculture, water resources, Himalayan region, coastal regions, health and disaster management.

Understandably, the impacts of climate change can only be deduced if there is long-term monitoring of habitats over time periods that are sufficient for these changes to be evident; such studies must also be accompanied by long-term monitoring of climatic factors such as temperature and rainfall at the same sites.

Work on Long Term Ecological Observations (LTEO) is being done in a number of developed and developing countries. India had been doing long term ecological monitoring only at one place in the country i.e. a fifty hectare plot at Mudumalai which has been monitored for the past over 30 years by Indian Institute of Science, Bangalore. Indian LTEO Programme will enable our scientists to join the international initiatives on the subject and provide credible empirical data on actual impacts on various ecosystems, thereby indicating the need for imminent adaptation measures.

It is with the above backdrop that my Ministry has prepared the LTEO Programme, which I am happy to launch under the ambit of Centrally Sponsored Scheme 'Climate Change Action Programme'.

I encourage Indian scientists to take part in this national endeavour, make best use of available research grants and produce first rate world class empirical data sets and results, which can bring both name and pride to India.

(Prakash Javadekar)

Paryavaran Bhawan, Jor Bagh Road, New Delhi-110 003
Tel.: 011-24695136, 24695132, Fax : 011-24695329
www.youtube.com/prakashjavadekar www.facebook.com/prakashjavadekar
www.twitter.com/prakashjavadekar e-mail :mefcc@gov.in
website : www.prakashjavadekar.com

अशोक लवासा
ASHOK LAVASA, IAS

सचिव
भारत सरकार
पर्यावरण, वन एवं जलवायु परिवर्तन मंत्रालय
Secretary
Government of India
Ministry of Environment, Forest and Climate Change

FOREWORD

Climate change is one of the biggest challenges facing humanity. As Earth continues to warm and weather patterns change in complex ways, there will be significant impacts on various natural and human systems including forests, grasslands, glaciers, wetlands, rivers, coastlines, agriculture, health, transportation, and energy, with serious implications for human wellbeing. India - an emerging economy with just 2.4% of world land area but with over 17% of the world's human population, 18% of the world's livestock population, 7-8% of all recorded species, and with four biodiversity hotspots (the Himalaya, the Western Ghats, the North-east, and the Nicobar Islands) is expected to be among the most vulnerable to climate change. We know that temperatures across India will increase in tune with the anticipated global trends, but we are still very uncertain of how patterns of monsoon, the lifeline of the nation, will change across the subcontinent. We have a broad idea of how forests and other natural vegetation may change during the 21st century but we have very little idea of how individual species and populations across our diverse biomes will respond to climate change. It is therefore imperative that we begin to scientifically understand in depth as to how climate change is impacting our biodiversity and ecosystems so that we may try to build climate resilience into our plans to conserve our rich diversity.

On the eve of 21st Conference of the Parties to the United Nations Framework Convention on Climate Change at Paris and during the United Nations Decade on Biodiversity 20 II-2020, I am happy to announce the launch of the Indian Long Term Ecological Observatories (ILTEO) Network that has been a long standing demand of our scientists. This programme will be implemented by the Ministry of Environment, Forest and Climate Change (MoEFCC) with the help of scientists from across the country. A key feature of this initiative is that it will cover all the major biomes of the country from Western Himalaya to the Western Ghats, Eastern Himalaya to Andaman & Nicobars, central India to the Sunderbans, and from Jammu & Kashmir to Rajasthan and Gujarat. The long-term scientific monitoring of the natural landscapes of the country, its waters, forests, grasslands, mammals, birds, herpetofauna, fishes, insects and traditional human socio-ecological systems, at representative sites will be carried out under a multi-disciplinary and multi-institutional framework. The focus would be to pick up signals and patterns of how changes in climate are affecting our natural and closely associated human systems of agriculture and pastoralism. More significantly, this programme will help build capacity within India in this important area of climate change impacts by training students and young scientists through sustained long-term support for research in these key areas. I therefore call upon the community of scientists in the country to respond positively to the call for proposals put out by the MoEFCC and help build the knowledge base for this important national effort.

Research on Climate Change is largely dominated by modellers and economists with futuristic projections. It is high time that biologists undertake targeted research with a view to discovering and compiling solid empirical data sets which separate the impact of change from background noise arising from local pollution, habitat fragmentation and climate variability.

I wish to put on record, the overall guidance and support provided by Shri Susheel Kumar, Additional Secretary and the diligent efforts made by Dr J. R. Bhatt, Scientist-G, MoEFCC in preparation of this document.

(Ashok Lavasa)

इंदिरा पर्यावरण भवन, जोर बाग रोड़, नई दिल्ली-110 003 फोन : (011) 24695262, 24695265, फैक्स : (011) 24695270
INDIRA PARYAVARAN BHAWAN, JOR BAGH ROAD, NEW DELHI-110 003 Ph. : (011) 24695262, 2465265, Fax : (011) 24695270
E-mail : secy-moef@nic.in, alavasa@nic.in, Website : moef.gov.in

सुशील कुमार
अपर सचिव
SUSHEEL KUMAR, IAS
Additional Secretary

भारत सरकार
पर्यावरण, वन एवं जलवायु परिवर्तन मंत्रालय
नई दिल्ली - 110003
GOVERNMENT OF INDIA
MINISTRY OF ENVIRONMENT, FORESTS & CLIMATE CHANGE
NEW DELHI-110003

PREFACE

From the mountains in the Himalayas to the islands off our coasts, India boasts some of the most dramatic landscapes. These house some of the highest numbers of unique species in the world. We are increasingly challenged to balance our valuable biodiversity and natural resources with the agricultural and economic needs of nearly 1.3 billion people. Protecting this balance in the face of global climate change is a high priority for India.

The Ministry of Environment, Forest and Climate Change is proud to announce the Indian Long Term Ecological Observatories (I-LTEO) programme. We now join many countries in the world in a global effort to understand, predict, and mitigate the effects of climate change on ecological and social systems. The focus will be to monitor the patterns and processes that regulate ecosystems in key biogeographic zones across the country. The I-LTEO programme stands apart from other long term environmental monitoring programmes in many parts of the world, as we begin the rigorous study of our ecosystems in their natural and complex socio-ecological settings. This programme aims to bring together the best scientists from the top scientific institutes of the country to conduct collaborative research. Coordinated by the Centre for Ecological Sciences at Indian Institute of Science, Bangalore, the I-LTEO programme will monitor natural vegetation patterns and carbon cycling, the distribution and movement of key faunal groups, and the hydrological and geochemical processes that underlie these systems. Equal emphasis will also be given to human dependence on ecosystem services and social-economic drivers, and how these are likely to respond to climate change.

Overall, the Indian LTEO programme will invest in fostering the country's ecological security. It is a timely and important step that will help remove uncertainties in our scientific understanding of nature's complex interactions, and how they impact human beings. It will offer a common platform for diverse groups of scientists to come together and offer the intellectual momentum to tackle one of the most formidable challenges of our times. Being inherently collaborative in its design, conception, and implementation, the Indian LTEO programme is uniquely poised to enable the country to move towards greater ecological security. India faces a wide variety of threats from climate change. With time, I-LTEO will enable India to gauge climate change impacts from the background noise and help in building a reliable database of observations and findings that will increase our confidence in predicting the impacts of climate change.

(Susheel Kumar)

इंदिरा पर्यावरण भवन, जोर बाग रोड़, नई दिल्ली-110 003 फोन : 011-24695242, फैक्स : 011-24695260
INDIRA PARYAVARAN BHAWAN, JOR BAGH ROAD, NEW DELHI-110 003 Ph. : 011-24695242, Fax : 011-24695260
E-mail : asmef.susheel@gov.in

Introduction

A. India's response to global climate change

Human caused climate change on a global scale is now recognized as an indisputable fact. The state-of-knowledge on the projected impacts of climate change, however, continues to be highly variable. With an economy closely tied to climate-dependent resources such as agriculture, water, and forestry, countries such as India have been identified as being particularly vulnerable to the effects of climate change. India may face major threats because of the projected changes in climate, both because of the large proportion of the population that is at risk, as well as the lack of fine-scaled information on which to base mitigation and adaptation measures. In particular, information is needed on how climate change is likely to alter the distribution and quality of natural ecosystems and resources, and the impacts this will have on the livelihoods of people.

To address some of these data deficiencies, the Ministry of Environment, Forest and Climate Change, Government of India, set up the Indian Network for Climate Change Assessment (INCCA), whose major objectives are to:

- Assess the drivers and implications of climate change through scientific research
- Prepare climate change assessments once every two years (GHG estimations and impacts of climate change, associated vulnerabilities and adaptation)
- Develop decision support systems
- Build capacity towards management of climate change related risks and opportunities

The network consists of a range of government and non-government institutions, universities and industry organizations working on issues of climate change. The scope of the programmes under INCCA will address core questions related to climate change, including but not restricted to:

- Short, medium and long-term projections of climate changes over India at sub-regional scales
- The impact of changes in climate on key sectors of economy that are important at various regional scales
- The anthropogenic drivers of climate change i.e., greenhouse gas (GHG) and pollutants emitted from various sectors of the economy
- The processes through which GHGs and pollutants interact with the climate system and change the biophysical environment

B. The Context of Climate Change

2.1 Climate Change Impacts and Projections

The importance of research on climate change was recognized in 1992 with the adoption of the United Nations Framework Convention on Climate Change (UNFCCC), whose ultimate objective was to achieve the stabilization of Greenhouse Gas (GHG) concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. According to the UNFCCC, climate change refers to the change in climate that is attributed directly or indirectly to human activity, beyond the natural climate variability observed over comparable time periods. The Fifth Assessment Report (AR5), 2014 of the Intergovernmental Panel on Climate Change (IPCC), concluded that the global average temperature increase in excess of 1.5 °C by 2100 relative to pre-industrial levels. Sea level may rise between 0.28 and 0.98m during this period.

According to the scientific studies conducted by the International Panel on Climate Change (IPCC), climate change may have serious impacts on a range of global-scale dynamics, including freshwater availability, ocean acidification, food production, flooding of coastal areas, and increased burden of vectors and water borne diseases associated with extreme weather events. Climate change therefore has been identified as one of the biggest challenges faced today by various stakeholders – policy makers, rural and urban communities and industries – as it is slowing down the pace of progress towards sustainable development either directly through increased exposure to adverse impact, or indirectly through loss of the capacity of the population to adapt.

2.2 Ecological limits to Climate Change and critical thresholds

Over the past three decades, climate change has been recognized as a major driver of biodiversity and ecosystem change. While common sense suggests that ecosystem responses to climate change will depend on the rate and magnitude of such change, multiple lines of evidence suggest that there are some critical ecological thresholds beyond which ecosystems may be unable to persist in their current states. Examples of such ecosystem shifts include the recent conversion of Arctic tundra to shrubland, desertification of tropical semi-arid rangelands, replacement of tropical wet forests by savannas, bleaching of coral reefs and sudden collapses of fisheries. More specifically, *an ecological threshold is the point at which there is an abrupt change in an ecosystem quality, property, or phenomenon, or where small changes in one or more external conditions produce large and persistent responses in an ecosystem.*

Ecological thresholds occur when external factors, positive feedbacks, or nonlinear instabilities in a system cause changes to directionally cascade through systems in a manner that is potentially irreversible. Once an ecological threshold is crossed, the ecosystem in question is often unlikely to return to its previous state. Such threshold responses are a challenge to ecological research that aims to predict ecosystem responses to climate change because they require consideration of a wider range of variables and time-scales than is the norm for most empirical studies. They also pose a serious challenge from the management perspective because they impose limits to social and economic adaptation to change and are often outside the bounds of local knowledge and experience of institutions and societies that must respond to them. Without doubt, research that targets the response of socio-ecological systems to such thresholds is an urgent priority.

2.3 Adaptability

Ecosystems[1] play an unequivocal and increasingly important role in both ecosystem-based mitigation (carbon sequestration and storage) and ecosystem-based adaptation (societal adaptation to climate change impacts). Healthy, fully functional, well managed, and adequately protected ecosystems can therefore achieve cost effective objectives for climate change mitigation, adaptation and long-term sustainability, whilst continuing to provide the essential ecosystem services on which we depend.

The events surrounding United Nations Climate Change Conference 2015 present an ideal opportunity to initiate a framework around which issues of climate change and environmental protection can be addressed and complementary solutions developed.

3. Need for Long Term Ecological Research Studies

A long-term ecological, social, and economic monitoring program is required to identify patterns and drivers of change, and to meet United Nation's Millennium Development Goals as hundreds of millions of people in India rely on natural ecosystems to sustain their livelihoods. Furthermore, monitoring is required to meet requirements and obligations respectively from enactment of national policies and signing of international treaties and conventions such as the United Nations Framework Convention on Climate Change (UNFCCC).

Across the world, various networks have been set up to integrate social and natural science disciplines in relation to climate change and sustainability, some of the leading networks are:

1. Long Term Ecological Research network set up by the National Science Foundation, USA (US-LTER), which considers the natural and social systems as a single, integrated social-ecological system. Over the past three decades, research at US-LTER sites spread across North America has generated valuable knowledge on the ecology of different ecosystems and biomes.
2. The successful US-LTER programme has resulted in the rise of several dedicated facilities such as the Nutrient Network (NutNet) across 40 countries that aims to understand general patterns in how ecosystems respond to different aspects of global change. More recent efforts also include the National Ecological Observatory Network (NEON) for North America that attempts to understand processes operating at the continental-scale. Other co-ordinated efforts at large scales include the Free-air concentration experiments (FACE) that addressed ecological responses to rising GHG in the atmosphere.
3. Similar programmes were also developed in Europe (International Long Term Ecological Research, ILTER). Initially, during the 1990s, these were modelled along the US LTER programme, and have recently evolved into the Long Term Socio-economic and Ecological Research (LTSER) covering 21 European countries; five other countries are scheduled to join the programme soon.
4. Over the last 20 years, countries from Central and South America (Chile, Brazil, Costa Rica, and Venezuela), Africa (South Africa, Namibia, Mozambique, and Malawi), Asia (Mongolia, China, South Korea, Japan, Thailand, Philippines, and Taiwan), and Australia have also joined the ILTER framework and initiated long-term monitoring programmes.

[1]Ecosystems encompass all land and marine based natural and semi-natural systems, and associated land uses including conservation, sustainable livelihoods, pastoralism, agriculture and forestry.

3.1 Long Term Ecological research in India: Current status and existing networks

The infrastructure and support for long-term research and monitoring in India has not always kept pace with other parts of the world. There is one established long-term research site for tropical forest ecology in the Western Ghats (50 hectare Mudumalai Forest Dynamics Plot) operated by Centre for Ecological Sciences, Indian Institute of Science, Bangalore, and its partners. In addition, there are some agencies involved with long-term monitoring of specific environmental variables, often in the absence of an over-arching co-ordinated effort. The National Institute of Oceanography, Goa (NIO), has run programmes to monitor biophysical characteristics of oceans. Likewise, Central Marine Fisheries Research Institute, Kochi (CMFRI), has monitored patterns in fish catch in the oceans. National Remote Sensing Centre, Hyderabad (NRSC), has monitored parameters of land cover and land use change through remote sensing technologies. Long-term research programmes on specific taxa have also been operated by different agencies such as Wildlife Institute of India (tigers), Nature Conservation Foundation (coral reefs), Indian Institute of Science and Dakshin Foundation (marine turtles). Even though isolated examples of long-term studies and monitoring programmes exist, there is an urgent need to develop a coordinated, national-level programme, specifically targeting social-ecological challenges arising from climate change under the aegis of the Indian Network for Climate Change Assessment (INCCA).

To address these needs, Ministry of Environment, Forest and Climate Change decided to launch the Indian Long-Term Ecological Observatories (ILTEO) as a constituent activity of the Climate Change Action Programme of the country. As multi-disciplinary and multi-institutional activity across the country's varied biogeographic zones, ILTEO proposes to incorporate ecological and social perspectives at the onset of developing the science plan. Each ILTEO site will have a research focus that will maximize understanding of the specific social-ecological system and the diversity of challenges that surround the research site; however, the ILTEO network of sites will also maintain a common minimum research programme. The Indian Long Term Ecological Observatories network will have the following goals:

1. To understand the ecology of major biomes / social-ecosystems at multiple spatial and temporal scales, through long-term and interdisciplinary research.
2. To inform scientific communities, policy makers and the public regarding drivers of climate related changes, and their implications for social-ecological systems.
3. To promote training and learning about environmental change through long-term social-ecological research and monitoring within India.
4. The fundamental research premise of the ILTEO network is to understand the biophysical and anthropogenic drivers of ecosystem change and their effects on social-ecological responses.

C. Climate Change and India

The quantum of India's total GHG emissions (including Land Use Land Cover Change) in 2007 was 1,727.71 million tonne of CO_2 equivalent, which is far lower than GHG emissions of China, USA and the EU. India's per capita GH emission in 2010 was 1.56 tonnes CO_2 equivalent, which is less than one third of the world's per capita emissions. The energy sector, agriculture, automobiles, and land-use change are major contributors to India's emissions. The country's ecosystems also experience the effects of altered climate.

The country has already witnessed an increase in average temperature over the last few decades (1971-2007). Average temperature during winter and post-monsoon seasons, on average across the country, have increased by about 0.8 °C and forecasts suggest an average increase of 1.4-1.9 °C over the next hundred years (INCCA 2010). According to the Second National Communication submitted to the UNFCCC by the Government of India in May 2012, it is projected that the annual mean surface air temperature of India may rise by 3.5 °C to 4.3 °C by the end of the century, whereas the sea level along the Indian coast is estimated to rise to about 1.3 cm/decade on an average.

Unlike temperature, where different climatological models offer consistent predictions, expected changes in precipitation are much more variable across regions and between projections. However, one aspect that is consistent across models and many parts of the country is increased frequency of extreme precipitation events. Most models also anticipate intensified summer monsoons that will lead to warmer and wetter future conditions in many parts of India. But, uncertainties associated with concomitant changes in potential evapo-transpiration make it difficult to predict the trajectories of how India's natural and agro-ecosystem will respond to such change in precipitation and temperature. A major challenge is to develop an understanding of responses of diverse ecosystems to simultaneous change in different aspects of global change – temperature, precipitation, atmospheric deposition of nitrogen and sulphur, etc. For example, even though net annual precipitation may increase, changes in seasonal distribution of precipitation coupled with rise in temperature can intensify aridity in the northern Himalayan, and other regions. Likewise, increased fire frequency and intensity in response to climate forcing may affect large tracts of the semi-arid and deciduous ecosystems. Widespread changes in vegetation cover and forest type, and marked redistribution of bioclimatic boundaries of biomes, are a real possibility that may have serious consequences for large human populations and livelihoods. The most recent work using the Integrated Biosphere Simulator (IBIS) suggest that about one-third of India's natural vegetation could change in character from one type to another by the end of this century. Epidemiology is another highly important dimension of future climatic scenarios for India. Several vector-borne pathogens such as malaria, dengue and chikungunya may experience suitable conditions year-round in many regions, and increase the country's burden of disease with projected changes in temperature and precipitation.

In many countries, protected reserves and national parks are used as ecological safeguards against anthropogenic disturbance and climate change. However, it is increasingly being recognized that these protected areas may be insufficient to protect natural resources in the future, In India, less than 5% of the terrestrial environment is secured under a protected areas network, and thus the conservation value of habitats outside protected areas needs to be actively considered. Such habitats not only include remnants of native vegetation but also active agricultural plots, plantation or managed forest, fallow land and gardens. In such coupled human and natural systems, the response of species are dependent upon the ecology of the species involved, the amount of habitat change, and the rate at which the species can adapt to changes in the environment. Heterogeneity in landscapes due to anthropogenic modification and fragmentation may negatively affect habitat specialists, while species which are tolerant of some modification in their habitat may persist up to a certain threshold. Monitoring the ecosystem in coupled human-natural systems is therefore essential.

Society as a driver and response

The increasing understanding that human and environmental systems are interlinked has resulted from studies that monitor both environmental and social parameters to explain global and local change. The LTEO programme in India will aim at monitoring change over time and recognize dynamics and impacts of social-ecological transitions (changes in the relation between social and ecological systems). These will incorporate a historic perspective while aiming to understand the drivers of and responses to change across varying scales.

To begin with, the Indian LTEO programme should focus on the following themes:

1. Socio-ecological systems: Biophysical flows are influenced by natural drivers as well as socioeconomic factors, which may operate at much larger spatial scales than local and regional biophysical processes.
2. Land use, landscapes and seascapes: Ecological and cultural information on the social and economic history of a region will be monitored. Variables would include economic activities, their spatial organization, settlement patterns, demography, mobility, and migration.
3. Communication and knowledge: Existing sources of information on resource use and conservation, processes of transmission and transformation of knowledge (scientific and non-scientific), communication systems and actors will be monitored.

Vision and Goals

Long-term ecological monitoring is necessary to understand the drivers and responses of climate change. From several recent studies of a global nature, it is becoming abundantly clear that short-term studies of 3-5 years (the typical duration of most funded science projects or a university doctoral thesis) is grossly inadequate to capture the inherent variability of natural systems driven by environmental stochasticity. Indeed, conclusions from such short-term studies can be completely misleading. Thus, it is necessary to monitoring changes in ecosystems and populations for many years or even a few decades before signals of climate change impacts begin to unambiguously emerge. The first phase of the common minimum ILTEO research programme will therefore focus on the most pressing drivers and responses of climate change by obtaining a baseline characterization of the environment, in order to understand ecosystem processes and change in the medium- to long-term.

Approach

A common minimum research programme will be established, where data on a set of ecological and social parameters will be collected at each of the selected field sites. The common set of parameters will serve as indices of change over the monitoring period across the sites. The sites have been selected to represent a wide range of habitats from coastal/marine to terrestrial, comprising the major terrestrial biomes in the country. In addition to the common programme, each site may also have a set of unique parameters that are either context- or habitat-specific. A common database platform will also be developed where data will be curated. This database will be hosted on an online server so that data entry or uploading of files can be carried out from any location.

Action plan

Long term field stations will be established in each of the representative regions. In order to collect data for the common programme, each station will be outfitted with the necessary infrastructure and equipment. For instance, a basic requirement for the ILTEO would be the establishment of a number of automatic weather stations, perhaps supplemented with cheaper data loggers for particular weather parameters such as temperature at additional locations. In addition, training will be provided to staff in the use of equipment, and in data collection and entry techniques. It will be necessary to ensure that data is collected using standardised methods and equipment, and that it is curated and entered on a regular basis into the national database.

The steps of establishing the ILTEO programme would involve:

1. Creation of a common minimum programme with specific parameters
2. Establishment or strengthening of field stations at each of the selected ILTEO sites
3. Installation of necessary infrastructure and equipment for each field station
4. Training and capacity building for the staff and researchers
5. Creation of national database for data entry and curation
6. Generating the scientific outputs in terms of data as well as critical analyses presented through reports and peer-reviewed publications.

ILTEO Sites

Map not to scale and without delineation of boundaries.

The fundamental objective of this network is to understand the biophysical and anthropogenic drivers of ecosystem change and their effects on social-ecological responses. The ILTEO programme would be site-based, covering the range of diversity and complexity of representative landscapes in the country to understand the link between climate change and ecological processes.

Given the wide range of ecosystems in India, spread across ten Biogeographic Zones (26 Provinces), the first phase of the monitoring programme will begin in the following regions:

1. Western Himalaya
2. Eastern Himalaya
3. North-Western Arid Zone
4. Central Indian forests
5. Western Ghats
6. Andaman and Nicobar Islands
7. Jammu and Kashmir
8. Sundarbans

The selection of specific sites within these zones are dependent on the following criteria:

1. Representativeness of the site for the Biogeographic zone.
2. Presence of existing long-term research stations or projects.
3. Logistic feasibility including the support of state government, local administrative bodies and regional scientific institutions.
4. Integration of the social matrix in the ecological context.

The second phase of the research programme will involve the establishment of ancillary monitoring stations to increase replicates for existing biomes, as well as the initiation of new ILTEO research stations that increase representation of understudied systems across the country.

Sites within the biogeographic zones (phase 1)

1. Western Himalaya

Western Himalayas represent a vast landscape that covers a large elevational gradient and corresponding changes in vegetation structure. The Himalayan foothills and Shiwaliks represent the low-lying areas (500-1000m approx.) that are covered by dipterocarp (sal or *Shorea robusta*) dominated deciduous forests. The mid-elevations (1000-2000m) are mixed broad leaf and conifer forests and savannas featuring conifers. Beyond 3000m is the treeline where the vegetation is dominated by alpine meadows. In the highest reaches, 4000m and above, the Western Himalayas are characterized by arid shrub-steppes found in Ladakh and Spiti. A transect from the Himalayan foothills in the Rajaji National Park, representing the subtropical deciduous forest habitat, to the higher elevation subtropical and temperate forests and grasslands in Kedarnath and Nanda Devi Biosphere Reserve in the state of Uttarakhand is representative of this remarkable variation. This can be extended northwards into the arid shrub-steppes of Spiti in Himachal Pradesh to cover the entire range of Western Himalayan habitats.

2. Eastern Himalaya

The Eastern Himalayan region is large and complex in topography and diversity. The range of habitat types is similar to the Western Himalayas in some respects, although the biogeographical and evolutionary linkages of the flora and fauna are distinct. Due to these differences, patterns of species richness and endemism in the Eastern Himalaya are high and it is recognized as one of the global biodiversity hotspots. In recent years, many species new to science have been discovered in this region, including mammals and birds. This highlights that much of Eastern Himalaya's biodiversity still remains unknown to science. Many of the endemic flora and fauna have restricted distributions, and their populations are threatened with extinction. Multiple sites will ideally have to be established here to capture this diversity but, in Phase 1, a transect from Pakhui Tiger Reserve in the foothills through Eagle Nest Wildlife Sanctuary and up to Tawang in Arunachal Pradesh will be established.

3. North-Western Arid Zone

Vast tracts of northwestern India fall under arid and semi-arid conditions. On average, the regions covered by the Aravalli-Vindhya ranges receive less than 1000mm of precipitation annually, and these include the deserts of Rajasthan. This region is important for conservation of iconic species such as the Great Indian Bustard. It also represents unparalleled examples of harmony between humans and wildlife: as evident from the Bishnoi community's reverence for nature. However, these semiarid and arid tracts are thought to be most vulnerable to ongoing and projected changes in the region's climate. A transect from Mount Abu to the Desert National Park in Rajasthan will capture a range of vegetation types including dry deciduous forest, thorn scrub and savanna, arid grasslands, and desert. Additionally, a similar transect from Gir National Park to the Rann of Kutch in Gujarat may also be established at a later phase to cover a similar gradient of vegetation types.

4. Central Indian forests

The Central Indian deciduous forests extend over a large area spanning several states covered by the Satpura range, Deccan plateau, and Chota Nagpur plateau. They represent one of the largest intact, though increasingly fragmented, stretches of dry and moist deciduous forests in the country. They are also home to one of the largest populations of tigers in the country.

These forests offer an opportunity to understand interactions between vegetation, herbivores, and predators, in the relative absence of severe human disturbance as many forests fall under the protected area network. In Phase 1, a transect including some reserves in Maharashtra and Madhya Pradesh, such as Tadoba, Pench, Kanha and Panna reserves will be established. The teak-sal transition zone in the region will be included in the monitoring plan.

5. Western Ghats

Broad latitudinal and elevation expanse enable the Western Ghats to support high species diversity and endemism, and it is recognized as a global hotspot. Large meta-populations of elephants and tigers occupy this landscape. However, one of the major threats is increasing fragmentation, with consequences for both wildlife and humans, with many forms of conflict scenarios. Like the Eastern Himalayas, species previously unknown to science, have recently been recently discovered in the Western Ghats: particularly reptiles and amphibians. The Nilgiri Biosphere Reserve, located centrally in the Western Ghats, includes an elevational gradient and a matrix of land use types and forest types (including tropical dry thorn forest, dry deciduous forest, moist deciduous forest, semi-evergreen and evergreen forest, montane grassland and stunted montane evergreen forest) within a good network of protected areas. This site has been the location of at least 30 years of previous long-term research on numerous taxa, including vegetation monitoring plots. Alongside the existing long-term site in the Mudumalai forests, adjacent sites will be incorporated to cover additional representative forest types of the Nilgiri eco-region.

6. Andaman and Nicobar Islands

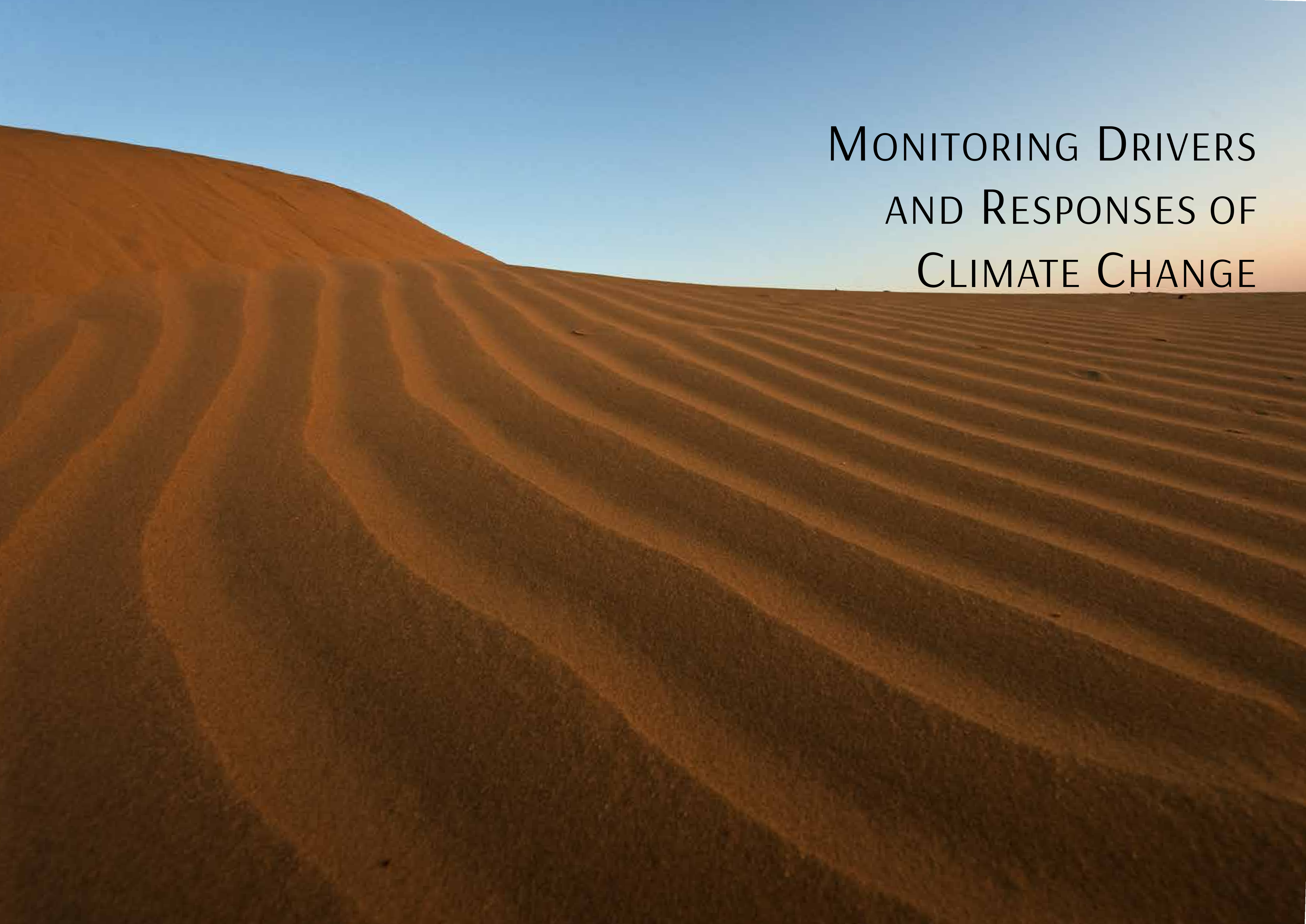
The Andaman and Nicobar group of islands in the Bay of Bengal comprise approximately 527 islands, islets and rocks, which in turn harbour vast stretches of fringing coral reefs. These reefs directly and indirectly contribute to the livelihoods and sustenance of a majority of the local human population. These reefs also harbour some of the most diverse coral reef and marine communities in the world. Recent years, however, have witnessed substantial degradation of these reef ecosystems by both natural and anthropogenic influences. Due to a recent detectable increase in sea surface temperature, the coral reefs of the Andaman group of islands have suffered a mass-bleaching event. The rich marine resources around the Andaman and Nicobar Islands also support several fisheries across the length of the islands. The inland and coastal habitats of South and Middle Andamans will be selected for their accessibility as well as representativeness of tropical evergreen forest and coastal/marine habitats including mangroves. The forests in South Andamans are the location of existing ecological research, as are the coral reefs in the areas in and around the Mahatma Gandhi Marine National Park and Rani Jhansi Marine National Park. Marine turtles and dugongs are being monitored in Little Andaman and Ritchie's archipelago respectively. The monitoring of terrestrial, inter-tidal and marine habitats will be included at these sites. The inter-tidal regions are important mangrove habitats.

7. Jammu & Kashmir

The landscape between the Hindukush and Himalayan mountain complex is a unique biogeographical, conservation, and evolutionary significance at both global and regional scales. These include areas covered by the Kashmir valley. Wetlands of this region are important for globally important migratory species, and many are designated as Ramsar Sites (e.g., Wular, Surinsar-Mansar, Hokera). Wetlands of this region are part of the Central Asian Flyway used by migratory waterfowl. Catchments of these wetlands are expansive and extend far into the adjacent mountains that support important agro-ecosystems. Horticulture and agriculture are important components of the region's ecology. Dal Lake and its catchment in the Dachigam National Park will be chosen as a monitoring site during Phase 1, given the history of research in this site over several decades. Monitoring of important wetlands in Kashmir region through the ILTEO programme will strengthen regional environmental planning to support ecological and economic sustainability.

8. Sundarbans

The Sundarbans is the largest congregation of mangroves in the world, and as a world heritage site and an International Biosphere Reserve. Sundarbans represent a coupled human-and-natural ecosystem that is ecologically linked to processes that occur at continental scale. For example, the Ganga-Bramhaputra hydrological catchments originate in the Western Himalaya and Trans-Himalaya, include the great plains of India and China, and culminate in the Sundarbans. This ecosystem is important for conservation of one of the largest surviving meta-populations of tigers. The low-lying deltaic landscape is also one of the most densely populated regions in the world. Fisheries and other forms of ecological use support nutritional requirements of very large human populations. They are also one of the largest mangrove ecosystems. Mangroves offer a variety of other ecosystem services, including buffering of erosion and other negative impacts of ocean and wind currents during seasonal cyclones. The role of mangroves in coastal protection has been stressed further after the Indian Ocean tsunami on 26th December, 2004. Mangroves offer a variety of other ecosystem services, including buffering of erosion and other negative impacts of ocean and wind currents during seasonal cyclones. This site will be included in the ILTEO as a representative of the connection between human livelihoods and biodiversity conservation.



Monitoring Drivers and Responses of Climate Change

Science Questions

The ILTEO will focus on the following three scientific questions, the starting point for which is future climate change:

1. How do changes in biodiversity and ecosystem services affect human outcomes (i.e. benefits to society)?
2. How do climate related changes in biodiversity and associated ecosystem function affect ecosystem services?
3. How does climate change influence biodiversity and key ecosystem processes?

Under these broad scientific questions, multiple research objectives will be carried out. The following are of priority for India:

1. Climatic variables (temperature, humidity, precipitation, solar radiation, wind speed, etc.) in relation to topographically complex landscapes.
2. River and stream hydrology in relation to climate and forest cover in catchments.
3. Groundwater levels and changes in natural ecosystems.
4. Carbon fluxes of natural and man-made ecosystems at the landscape scale.
5. Carbon stock changes in soils associated with different forest types and land use patterns.
6. Vegetation and land-use patterns and changes at the landscape scale through remote sensing.
7. Forest and grassland dynamics in relation to environmental factors through permanent plot studies.
8. Sensitivity of tree species to climate variability through eco-physiological studies.
9. Ecology and management of invasive alien plants and animals.
10. Fire ecology and management of different vegetation types.
11. Spatio-temporal changes in animal diversity (e.g. key insect groups, reptiles, amphibians, birds, and small mammals).
12. Shifts in species distributions along altitudinal and latitudinal gradients from past records and present patterns.
13. Wildlife behaviour and movement at the scale of landscapes.
14. Changes in human use of natural landscapes and agricultural patterns with reference to socioeconomic change and changing climate.
15. Management of natural resources in the context of changes in climate in human dominated landscapes.

Ilteo research programmes

The specific objectives above will be studied by multi-institutional research teams that focus on research programmes surrounding the following themes. Each programme will be conducted at all the ILTEO sites, wherever applicable, and will generate large-scale and long term data for each of the following:

1. Generating biophysical climatic variables
2. Generating land-use and land cover change
3. Monitoring hydrology of the site catchments
4. Monitoring the biota of freshwater lakes and their catchments
5. Monitoring forest structure and dynamics
6. Monitoring grassland community dynamics
7. Monitoring soil processes in forests and grasslands
8. Monitoring large carnivore and herbivore populations
9. Monitoring medium and small mammal populations
10. Monitoring bird populations
11. Monitoring herpetofaunal populations
12. Monitoring freshwater fish populations
13. Monitoring selected arthropod taxa
14. Monitoring animal movements across multiple spatial scales
15. Monitoring coastal and marine ecology, including mangroves
16. Monitoring traditional socio-ecological systems

Research programmes and the monitoring approach

A number of broad themes have been identified for the purpose of organizing the research programmes for the ILTEO, and for inviting proposals from teams of scientists with expertise in these themes. It is anticipated that at least one research project, involving a team of scientists working across different sites, would be funded, and that several projects would be funded under some themes. It is important to develop synergies not only within each research project or theme, but also across themes such that a more holistic and deeper understanding of climate change impacts on ecological systems is derived. Thus, research projects on the various themes will have to be organized around a set of common locations where weather monitoring stations will be located, and where the permanent plots for monitoring forest (including mangroves) and grassland dynamics will be set up.

1. Generating biophysical climatic variables

Fine landscape-scale bioclimatic data is absent for much of India, especially in regions of complex topography where they are most needed, and thus each ILTEO site will be fitted with automatic weather stations that record the necessary biophysical climatic variables. These weather stations will have data loggers to monitor temperature, rainfall, humidity, solar radiation, wind speed, soil moisture, and other relevant parameters. The number of such weather stations at each site will depend on altitudinal span, topographic complexity, and climate variability across the landscape. Portable instruments such as CO_2 analysers will also be used to provide information at the micro-scale. A CO_2 flux tower is also eventually planned for these sites where feasible.

2. Generating land-use and land cover change

Remote sensing data can be used to understand how natural and manmade systems change over time as a result of climate variability as well as anthropogenic factors. Satellite imagery at multiple resolutions will be used to generate vegetation and land use maps of the site each year. At the coarser scale ~30 m resolution, multi-spectral data will be used, while at the 1 ha scale, hyper-spectral data as well GeoEye panchromatic data will be the used. Vegetation and land use maps of the site will be generated each year based on supervised classification of the imageries. Detailed maps of the ILTEO sites are proposed to be made based on satellite imageries. When available, LIDAR data corresponding to the site will be opportunistically obtained for fine-scale vegetation and carbon mapping. For each of the site, historical time-series of monthly NDVI data (AVHRR and MODIS) will also be acquired for assessing changes at the site over the past few decades.

3. Monitoring hydrology of the site catchments

In each of the sites, the catchments corresponding to the site will be identified. Surface and sub-surface hydrology, micro-meteorology and plant-water relations will be analysed either at the catchment scale and/or the tree plot scale.

The sampling scheme will ensure that the rain and stream gauging covers various spatial scales, land-cover mosaics and rainfall intensity regimes. For example, the upper basin (> 300MSL) of the river basin corresponding to the site will be delineated at each site. A nested scheme of 10x10km, 5x5km and 1x1km grid cells within this will be used. One 10x10km grid cell in each basin will be selected for detailed hydrologic measurements using a nested network of gauging stations from first order to third order streams in a manner that it covers homogeneous land-cover catchments (<50 ha) at the first order stream to heterogeneous catchments at higher orders. Hourly and daily data from the nearest India Meteorological Department's and other rain gauging stations within and around the 10x10km grid will also be obtained. Synoptic weather charts and maps will be obtained to correspond to measured rain storms and historic time-series of rainfall intensities.

This nested approach will help assess the thresholds of scale beyond which impacts of land cover and land cover change are over-ridden by extreme rain events on storm runoff hydrology. Synoptic weather charts and maps will be obtained to correspond to measured rain storms and historic time-series of rainfall intensities. Small catchments at the lower order scale (<50 ha) each under relatively homogeneous natural forest, degraded forest, reforested and cultivated areas, will be the focus of intensive data collection within the catchment apart from rainfall-streamflow measurements. Approximate water balance method will be used to estimate evapotranspiration using available climatic and streamflow data.

The catchments will be mapped intensively for disturbance and human-use, especially, roads and trails. In these small catchments, a grid of 1 ha will be imposed and utilized for intensive sampling of soil hydraulic conductivity (permeameter), soil moisture (Time Domain Reflectometer), soil water potential (tensiometers) and soil physical properties (bulk density and texture) at depths up to 1 m. These 1 ha plots will also be utilized for eco-physiology measurements of tree-water of ten trees of dominant species as well as water vapour flux from the canopy using bowen ratio or eddy-correlation methods. A ground-water monitoring well will be established at the highest and lowest water gauging station to monitor temporal variability in groune-water levels. Water quality parameters in surface and ground-water including nitrate, bacteria, total dissolved solids, and phosphates, will also be measured.

4. Monitoring the biota of freshwater lakes and their catchments

Given the importance of wetlands to ecosystem services and to water security for the human population, the impact of climate change on freshwater lakes and their catchment areas is of national importance and will be incorporated as a component of the ILTEO. Physical, chemical and biological parameters of the lake, including water temperatures, pH, BOD, etc will be monitored along with population status of native and introduced/ invasive biota. This work will be combined with hydrological and biological monitoring of the catchment of the lake.

Physico-chemical attributes of water quality are robust indicators of wetland ecosystem function and status. Wetlands are also susceptible to various forms of disruption through human interventions, most importantly eutrophication. Land-use change, agricultural practices involving fertilizers and pesticides, insufficient waste-water management, and other factors in far-away places can ultimately alter wetland functioning. Changes in phytoplankton and zooplankton in response to eutrophication has wide ranging impacts on ecosystem services supported by wetlands. Wetlands are very productive, and biomass buried as sediments is an important carbon sink. Slow decomposition of sediments is also a source of methane. Changes in physico-chemical attributes of wetlands can readily affect the net storage of greenhouse gases and other ecosystem services. In many cases, these are sinks are eliminated when wetlands are drained to give way for alternate land-use.

Initially, monitoring of wetland ecology will be focused on Dal Lake and its catchment, and will build on the considerable work already carried out there in the past decades.

5. Monitoring forest structure and dynamics

Long-term (>30 years) vegetation monitoring plots around the world continue to reveal the subtle ways in which forests are changing over time in response to changing environmental drivers. For example, in some forests in the world, long-term monitoring has shown a consistent trend towards drought-tolerant species and greater representation of tree species with increased average wood density. These changes are reflections of altered ecosystem functioning and services. The need for an extensive network of long-term vegetation plots is particularly high in a country like India, which has a great variety of climates, soils and forest types. The importance of such plots is best highlighted by the 50 ha Mudumalai Forest Dynamics Plot, which over twenty-seven years of monitoring by Centre for Ecological Sciences, Indian Institute of Science, has yielded key insights into the factors regulating tree mortality and recruitment, and the role of fire, drought, and elephants in regulating the dynamics of dry-deciduous forests. But in the absence of similar efforts in other habitat types, it remains unclear whether the patterns observed in Mudumalai necessarily hold true for other forest types or even other deciduous forests in the country.

Vegetation plots that are part of the ILTEO network would include the potential objectives: (a) to characterize how forest structure, species diversity, and biomass changes across broad environmental gradients, (b) to determine how forest stand structure and dynamics relate to local climate and soil characteristics, (c) to quantify long-term changes in species populations, community composition and forest biomass, (d) to quantify patterns of above-ground and below-ground carbon and nutrient cycling in plots, and (e) to document phenological patterns and quantify long-term changes in phenology. In addition, physical factors such as geomorphology, tidal patterns, and rates of freshwater inflow will be important parameters in monitoring of mangrove forests.

Permanent long-term monitoring plots of 1-3 hectares each in different forest types will be set up. Plots will be identified and marked following standard protocols (e.g., the Centre for Tropical Forest Science's protocols being followed at Mudumalai are now recognized as an international standard for such work). Plots will be placed in relatively undisturbed stands that are homogeneous and well-represent the native habitat. Within the plot, all plant stems that are >1cm diameter at breast height (dbh) will be tagged, identified, measured and plotted onto a map. Demographic changes in these plants will be monitored, and changes evaluated against site-specific differences, and regional climate trends. Dendro-chronobands will also be installed on a subset of trees of different species to monitor growth patterns of trees in the sites. Plots will be re-sampled periodically and the data analysed to quantify how plant demography (recruitment/regeneration, stem growth and mortality) changes across species, and across time as a function of changing climatic drivers (rainfall, temperature, fire etc), and how these in turn scale-up to determine patterns of biomass accumulation in sites.

6. Monitoring grassland community dynamics

Grasslands and similar ecosystems are a major biome across the globe, and dominate the sub-humid regions. In India, they are a major source of ecosystem services as they support a large livestock population, as well as a wide variety of wildlife. They are the climax vegetation in some ecosystems (e.g., alpine meadows, arid steppes). In many other places, they represent seral stages as part of a matrix of alternative habitats (e.g., within mix of forests, savanna, cropland). Unfortunately, grasslands have been historically neglected, despite their high ecological and societal relevance, and have often been subjected to inconsistent policy decisions. They have frequently been designated as wastelands, resulting in land-use conversion.

Monitoring of grassland ecosystem structure and function will involve establishing permanent plots that cover the spectrum of current land-use and disturbance regimes. Fire and grazing are the most common features. Permanent plots, with associated controls when applicable, are a globally standardized source of information on their dynamics. Burnt/unburnt plots and grazed/ungrazed plots represent such paired sets, and these will be monitored across representative grassland sites. Data on species composition, biomass, and soil nutrient status will be collected seasonally, and annually, using standardized protocols from replicated 10m x 10m plots.

7. Monitoring soil processes in forests and grasslands

Soils are fundamental to the functioning of all terrestrial ecosystems. Material and energy flow through ecosystems are broadly controlled by biological and geological properties of soil. Vegetation and soil carbon, and nutrient pools and fluxes in the permanent forest and grassland plots described above will be quantified to evaluate the biotic and environmental controls over energy and nutrient cycling in plots. In addition, all sites will be instrumented to quantify levels of N & P deposition, both wet and dry. This is critical both for quantifying levels of deposition at sites - data for which are scarce in the Indian subcontinent - as well for interpreting responses of vegetation in the long term.

Soils are a major sink, as well as source, of greenhouse gas emissions. Most important gases are carbondioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Release and/or storage of carbon and/or nitrogen in these forms from soil represent broad biogeochemical patterns across global scales. Portable gas analysers will be used to assess the rate of emissions of CO_2, CH_4, and N_2O, from soil across habitats, covering wide ranges of environmental conditions (soil type, regional climate, land-use). This will be a crucial step towards assessment of the mutual feedback that operates between soils and ecosystem structure and functions. Soil moisture probes will be installed to characterize changes in soil water content over time. Following plot establishment and inventory, soil cores will be collected from within the plot for laboratory analysis of physical properties (e.g., soil texture) and chemical properties (carbon:nitrogen ratio).

Plant carbon and nutrient pools will be estimated based on chemical analyses of plant tissue, and fluxes determined by combining these with plant production estimated using allometric equations from tree growth data. Soil carbon and nutrient pools will be quantified based on chemical analyses of soils. Soil carbon fluxes will be determined by quantifying soil respiration rates, while soil nutrient fluxes will be evaluated based on estimating monthly mineralization rates using open-top mineralization tubes.

8. Monitoring large carnivore and large herbivore populations

A number of faunal groups will be monitored to determine long term changes in abundance, community structure, diversity and functionality in the representative ecosystems. Large mammals such as the elephant and the tiger are keystone species of tropical ecosystems or at the apex of the food pyramid. At the same time, a number of other large-bodied herbivores (e.g. gaur, sambar deer, chital, nilgai, chinkara, black buck) form prey for the top-predators, while other carnivores (e.g. leopards, clouded leopard, dhole) either compete with the top predator (tiger, lion) in complex dynamics or perform the role of the top-predator in many ecosystems. Monitoring these populations using a combination of methods such as line transects, camera traps, DNA-based methods, and occupancy models would be essential at each site.

Repeated long-term sampling of large carnivores (e.g. tigers, leopards, lions) and the large hebivore populations that comprise their prey can be conducted using DISTANCE sampling techniques. Monitoring of several species of large carnivores, especially those with distinct morphological patterns, is possible using targeted camera trapping (separate from meso-predator surveys) and sophisticated Mark-Recapture analysis techniques. The resulting data on distribution and demography of large mammals will be a key component of the ILTEO.

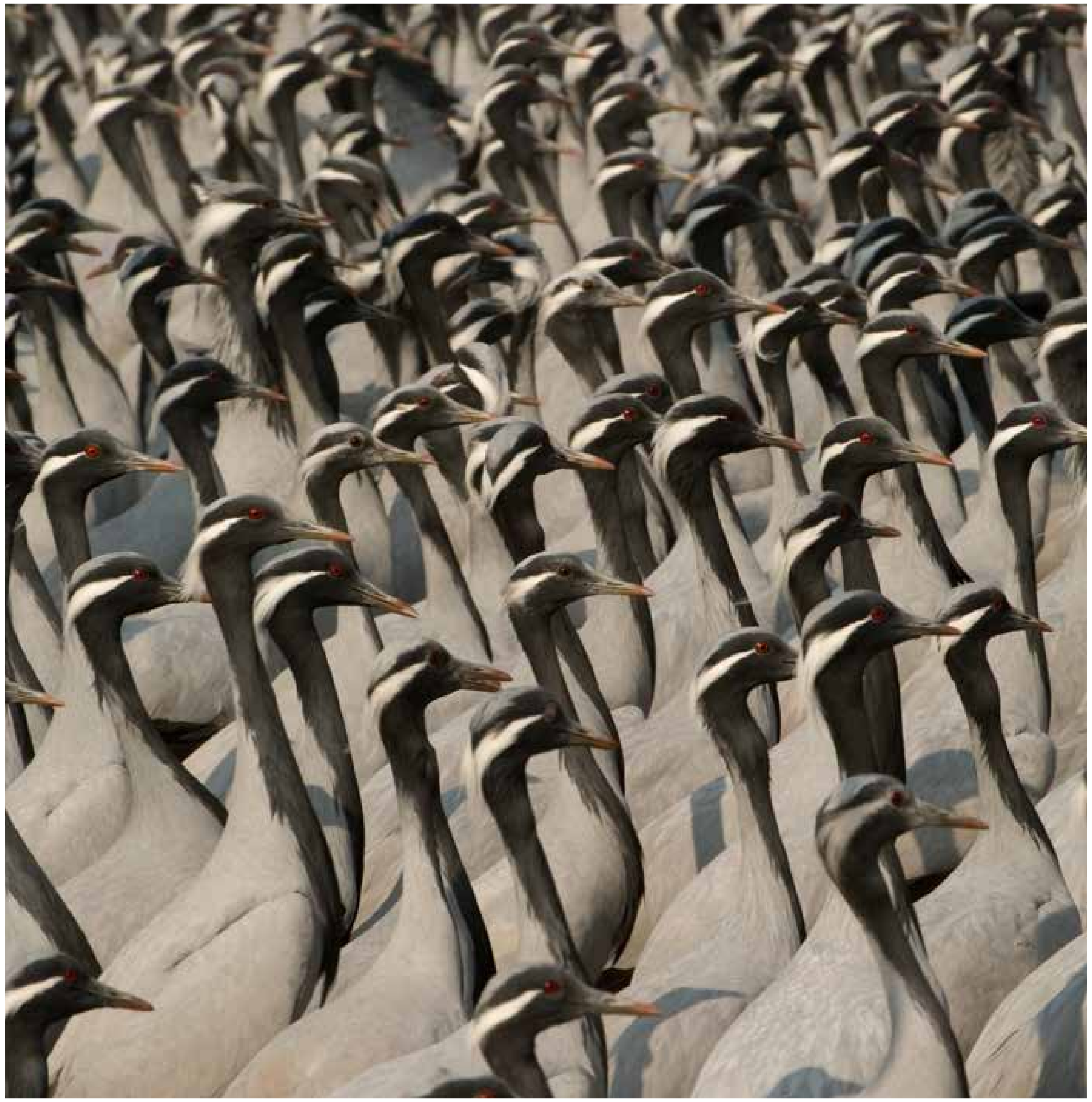
9. Monitoring medium and small mammal populations

Small mammals (leporids, rodents) are integral components of several ecosystems because of their roles as consumers of plants, seeds and arthropods, as soil disturbance agents. Small mammals are also primary food for raptors, snakes and mammalian carnivores. Because of their abundance, relatively short lifespan and high population turnover rates, their response to changes in the environment is not only likely to be the most visible among the mammals, but also relatively more easily measurable. Small mammal monitoring will be carried out through 2-3 surveys per year of trapping webs or transect lines using live-catch traps. Captured animals will be tagged (preferably with PIT tags) and released to enable estimation of densities and other life-history parameters. For medium-sized mammals, non-invasive survey techniques will be used to obtain indices of relative abundance and site occupancy estimates. These techniques consist of baited or scented camera trap stations and track-plate stations.

10. Monitoring bird populations

Birds are ubiquitous, easily identifiable, and high in the food chain, and thus are excellent indicators of environmental change. Long term information on bird communities, populations, demography, movements and long-distance migration has been used in many parts of the world to gain detailed information on the effects of climate and habitat change. To monitor bird populations and communities, permanent line transects or fixed point counts will be established. Because these transects will be walked frequently or the fixed points monitored through the year, information on the timing of migration will also emerge. To unpack the influence of survival and reproduction on population outcomes, it is also important to monitor demographic processes.

This will be done through establishing permanent plots at each ILTEO site, within which mistnetting and ringing will be carried out during defined periods. Pulses of netting of above a week's duration will be carried out, and these pulses will be distributed at four evenly spaced intervals across each year. By analysing these data using robust mark-recapture techniques, it is possible to estimate population densities, survival rates and reproductive rates. Measuring the latter two vital rates is crucial if one is to understand the causes of population change over time.



11. Monitoring herpetofaunal populations

Climate change, pollution and disease have ravaged amphibian populations in many parts of the world. Disease due to a fungal pathogen has caused widespread decline and extinction of amphibian populations across the globe especially in the neotropics. Recent research has identified high risk areas for the spread of this pathogen which includes biodiversity hotspots like Western Ghats in the Indian subcontinent, an area of high local endemism with most species restricted to a single hill range and narrow elevational bands.

Amphibians can serve as early warning systems for environmental changes due to global and local drivers such as climate change and pollution. The more abundant species of amphibians and reptiles can be monitored across time and space to provide an index of change. Visual searches and acoustic searches can be employed to record the presence and absence of select frog species during the breeding season.

In addition, distributions and occurrence of rare species will be monitored over time. Some species are restricted to the canopy and mostly identified by their calls; these species can serve as indicators of canopy health. Recent studies have revealed that amphibians in streams in the Western Ghats (as elsewhere in the world) have morphological abnormalities, which can be recorded. While the underlying stressors which lead to the abnormalities are not yet known, it is possible that the presence/proportion of abnormalities could be used as an index of environmental/anthropogenic stress.

12. Monitoring freshwater fish populations

Many fish are sensitive to environmental change and can serve as excellent indicators of habitat and ecosystem health. Given the importance of, and the rapidly declining health, of freshwater ecosystems, it is necessary to monitor these habitats. Freshwater fish are characterised by a high degree of endemism, and the presence and abundance of these endemics can be quantified to measure responses to various impacts. Industrial and agricultural effluents into freshwaters, introduction of invasive species are some of the primary disturbances to freshwater habitats and their assemblages. Fish can play an important role as indicators of such disturbances to freshwater habitats. For example, ecotoxicological studies can help detect movement of polluting heavy metals into the food chain, while changes in population dynamics of sensitive species can be used to study the effects of invasive species. In addition to providing basic information on ecological factors that structure biotic communities, long term collection (that includes seasonal and spatial monitoring) can provide baselines for testing effects of natural and anthropogenic disturbances. These will help in making informed decisions for freshwater conservation and management.

Fish can be monitored by observing catch in fishing communities, and by conducting periodic fish sampling using standard nets and effort. Parameters such as presence/absence of indicator species, abundance of select species, and body size can be used to monitor trends in fish populations. In addition to providing basic information on ecological factors that structure biotic communities, long term collection (that includes seasonal and spatial monitoring) can provide baselines for testing effects of natural and anthropogenic disturbances.

13. Monitoring selected arthropod taxa

Insects make some of the most informative and sensitive indicators of climate change. For a long-term monitoring program to study the effects of climate change on biological diversity and ecosystem functioning, the following characteristics are essential to incorporate. The insect groups should be broadly interconnected in ecological communities and ecosystems, sensitive indicators of environmental and ecological change, relatively conspicuous and easy to sample, taxonomically and ecologically well-studied with standard sampling methods, and ecologically diverse with variety of life history strategies. Thus, the following target insect groups will be included:

1. Social insects from the Hymenoptera, especially Bees that are important pollinators, and ants that are numerically dominant and diverse group of insects in most terrestrial ecosystems.
2. Butterflies and select families of Moths (Lepidoptera) that are dominant invertebrate herbivores, prey to diverse predators, show high diversity and endemism, and high host-plant and habitat fidelity.
3. Cicadas and Lantern flies (Hemiptera) that are known for their periodicity and/or dependence on seasonally changing climatic conditions.
4. Dragonflies and Damselflies (*Odonata*) for aquatic ecosystems because of their high endemism, high habitat and landscape specificity, and complex life history.

Research on insect groups will focus on phenology of insects and associated plants, population monitoring to study seasonal and yearly fluctuations in population sizes, and impact on reproductive biology.

14. Monitoring animal movements across multiple spatial scales

Besides diversity, distribution and demography of key faunal groups, behavioural processes, such animal use of the landscape, are expected to be highly sensitive to climate change. In fact, changes in habitat use and movement strategies are likely to be the first detectable shifts in animal responses to climate-related changes in the environment. For instance, elephants are known to disperse widely and come into conflict with people and agriculture during years of drought. Thus, an understanding of how willing species are to traverse or even utilize potentially inhospitable and risky habitats is critical to understanding coexistence and survival strategies. The ILTEO will employ advances in the field of movement ecology to understand how animals are utilizing the fragmented and changing human-dominated matrix.

The field of movement ecology has seen considerable advances in the last five years. The analysis of movement data has thus moved on from simple descriptions of home-range and habitat use to more complex ecological parameter-driven models of canonical movement modes. Different environmental factors and scales may influence the movement of individuals within a landscape, and therefore animal-landscape relationships will be examined across a range of scales. The study of movement ecology of key taxanomic groups using GPS technology will be targeted at the ILTEO sites. Medium-sized carnivores, typically occupying the meso-predator guild, are key determinants of diversity and population sizes of lower trophic level organisms such as small mammals, birds, herpetofauna etc. The primary knowledge for many meso-predators is lacking in India and thus telemetry studies with key species will be carried out at all ILTEO sites. Additional taxa such as elephants and other large herbivores that are keystone species will also be studied with this approach.

15. Monitoring coastal and marine ecosystems

Coastal and marine ecosystems, including mangroves, are under increasing pressure due to anthropogenic impacts including resource use, coastal development, pollution and climate change and associated sea level rise. Given the importance of marine biodiversity and the dependence of coastal communities on these resources, it is imperative that these ecosystems are monitored in the long-term. Coastal and marine monitoring can be divided into physical and biological components. For coastal ecosystems, it is necessary to monitor shoreline changes in response to developmental activities and sea level changes, as well as change in distribution and structure of mangroves. For coastal ecosystems, it is necessary to monitor shoreline changes in response to developmental activities and sea level changes. Temperatures need to be monitored, particularly in the context of impacts on endangered species such as marine turtles, where hatchling sex ratios are determined by temperature and in the context of impacts on entire ecosystems (such as coral bleaching). Upstream changes can have substantial impact on coastal systems and thereby it is necessary to monitor sediment load and organic and inorganic pollutants that can have severe impacts on critical coastal ecosystems such as coral reefs and seagrass beds. Biologically, it is necessary to monitor abundance and diversity, population demography and dynamics as well as ecosystem processes.

Mangroves are an important component of India's coastline. They form a dynamic ecotone between ocean-continent interfaces and are constantly subjected to changing hydrological, geological and ecological factors. Against the backdrop of global climate change and rising sea levels, conservation and restoration of these coastal forests is crucial. For this, structure and distribution of mangroves will be monitored through permanent plots and remote-sensing applications.

Simple protocols can be used to conduct beach profiling, and can be repeated seasonally or annually to monitor changes in the width, height and slope of beaches. Air, sand and water temperatures will be monitored in the context of impacts on ecosystem, as also sediment load and organic and inorganic pollutants. Long-term monitoring of marine ecosystems such as intertidal rocky shore ecosystems, coral reefs and seagrass meadows will be carried out using permanent plots. Coral reef cover will assessed at index sites in the Andaman and Nicobar Islands. Simultaneously, predation and herbivory assays can also be carried out to measure and track ecosystem processes. In addition, novel monitoring techniques using automated reef monitoring structures will be initiated.

Long term monitoring programmes of endangered species such as marine turtles and dugongs will be continued at index sites. Monitoring of other endangered species such as sharks and groupers will be initiated in the Andaman and Nicobar Islands.

Monitoring of fishery resources will be carried out in collaboration with local organisations, institutions, groups and communities; parameters such as body size provide a good index of population trends, while data on catch composition can provide insights into the spatio temporal changes in population/community structures. While monitoring fisheries, it is also necessary to monitor bycatch, as this can indicate impacts on endangered species, as well as provide insights into the status of the fishery itself.

16. Monitoring traditional socio-ecological systems

India's human-dominated landscapes represent a diverse mixture of agricultural land, fisheries, plantations, and rangelands. These are faced with diverse and variable threats related to climate impacts. India's socio-ecological ecosystems are of utmost importance since they provide food, fibre, timber, and fuel to one of the largest human populations in the world, and also for critical overseas trade partnerships to make a significant contribution to the country's economy and the livelihoods of its people. These ecosystems include farmlands, plantations, grazing lands, aquaculture and fisheries, among others. India has the world largest livestock population consisting of cattle, buffalo, goat, sheep, camel, yak, swine, poultry, and other species and varieties that are also of unique anthropological importance in supporting diverse forms of pastoralism (nomadic, trans-humance, intensive ranching etc.). Livestock not only face, but also create many ecological problems. Desertification is believed to be a consequence of changing livestock husbandry patterns in many areas. In other areas, pastoral livelihoods are at risk due to changing climate. Pastoral livelihoods are often inconsistent with aims of biodiversity conservation since livestock often fall prey to endangered carnivores such as the tiger and the snow leopard, leading to severe human-wildlife conflict.

India's social-ecological ecosystems are also critically dependent on ecosystem services provided by different native species including pollination services, pest control, and seed dispersal by insects and birds and other animals. Many varieties of crops are solely dependent on native pollinators, and recent declines in their populations are a cause of severe concern. Insectivores such as birds and bats provide immeasurable benefits through bio-control of agriculturally important pests, and there is an urgent need to establish monitoring protocols across the country for populations of such species that provide valuable ecosystem services.

Monitoring of factors related to water availability (precipitation, temperature and evapo-transpiration) will be important for various agricultural and silvicultural ecosystems. Monitoring of population status of pollinators, their species composition, as well as the status of disease-causing agents for bees and other insects, is of relevance for a variety of crops. Similarly, in terms of pest control, population status of bats and insectivorous birds will be monitored, particularly for areas where multiple land-use practises exist as a matrix. Crop damage by wildlife in such scenarios is a serious form of conflict that compromises human livelihoods as well as conservation. Factors related to the extent and intensity of crop-damage (e.g., cropping patterns, seasonality, demography of crop raiding animals, and habitat characteristics that either promote or discourage crop-raiding) will be monitored. Parameters related to regional hydrology, and nutrient run-off from agriculture and other matrix of land-use, will be important for inland and coastal fisheries. Measurements of soil nutrient status, grazing intensity, and vegetation composition will be emphasized for rangelands that are important for livestock production.

Implementation Design and Coordination

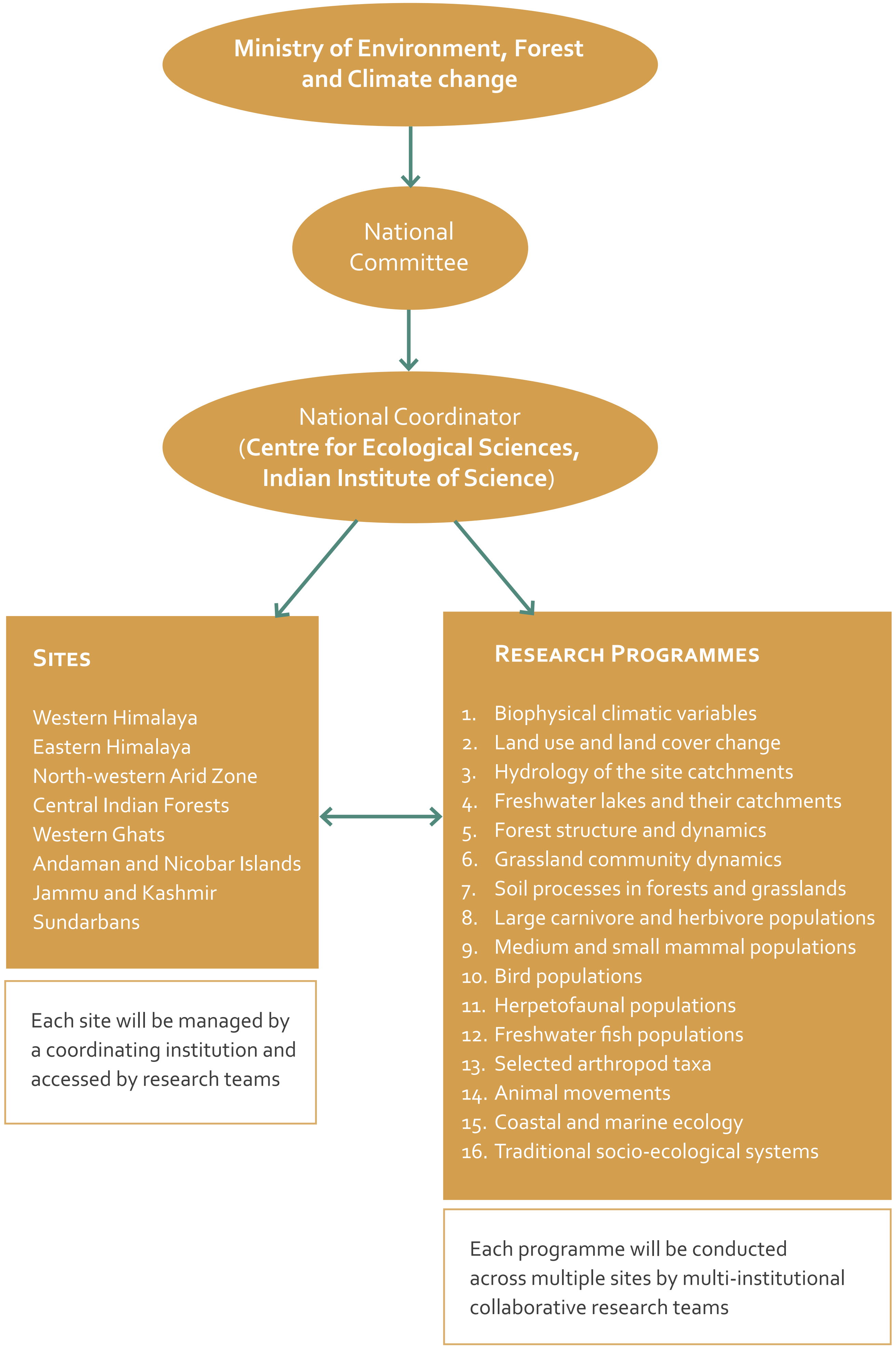
6.1 Institutional arrangement

The Indian LTEO programme will be funded and operated through the Climate Change Division of the Ministry of Environment, Forest and Climate Change, Government of India. As the programme is complex, and spread over a large geographical area, the network of scientists involved in the programme will inevitably come from scientific institutions and groups across the country. Therefore, an interdisciplinary team of scientists and institutions, each with skills in one or more disciplines, with adequate geographical representation is proposed to be established.

The national scientific programme will be coordinated through a cell established within an institution with expertise in several disciplines covered under the ILTEO. Research at each site will be coordinated by a regional institution with easy access to the site or by an institution or research group that already have significant research presence and facilities at the site. Institutions that will play the coordinating role for the national-level scientific effort and the site-level logistics will be selected by the Ministry of Environment, Forest and Climate Change.

It is also proposed that the long-term monitoring across sites of various scientific themes mentioned above will be coordinated by a single research institution/group, even though the work itself may be carried out by a number of research teams.

Apart from government departments such as Ministry of Environment, Forest and Climate Change, Department of Science and Technology, Department of Biotechnology, and National Biodiversity Authority, several other government agencies, institutions, universities and non-government research organizations across the country will be involved in this national effort.



References

Corlett R.T. 2012. Climate change in the tropics: the end of the world as we know it? Biological Conservation 151:22-25.

Constanza, R., R. d'Arge, R. deGroot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R.V. O'Neil, J. Paruelo, R.G. Raskin, P. Sutton & M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. Nature 387:253-260.

Grimm, N.B., J.M. Grove, S.T.A. Pickett & C.L. Redman. 2000. Integrated approaches to long-term studies of urban ecological systems. BioScience 50:571-584.

Haberl, H., V. Winiwarter, K. Andersson, R.U. Ayres, C. Boone, A. Castillo, G. Cunfer, M. Fischer-Kowalski, W.R. Freudenburg, E. Furman, R. Kaufmann, F. Krausmann, E. Langthaler, H. Lotze-Campen, M. Mirtl, C.L. Redman, A. Reenberg, A. Wardell, B. Warr & H. Zechmeister 2006. From LTER to LTSER: conceptualizing the socioeconomic dimension of long-term socioecological research. Ecology and Society 11(2):13.

IPCC, 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, IPCC, Geneva, Switzerland.

Magurran, A.E., S.R. Baillie, S.T. Buckland, J.M. Dick, D.A. Elston, E.M. Scott, R.I. Smith, P.J. Somerfield & A.D. Watt. 2010. Long-term datasets in biodiversity research and monitoring: assessing change in ecological communities through time. Trends in Ecology & Evolution 25:574-582.

Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: Synthesis. Washington, DC: Island Press.

Myers, N., R.A. Mittermeier, C.G. Mittermeier, G.A.B. Da Fonseca & J. Kent. 2000. Biodiversity hotspots for conservation priorities. Nature 403:853-858.

NCCA. 2010. Climate change and India: a 4x4 assessment, a sectoral and regional analysis for 2030s. Ministry of Environment and Forests, Government of India.

Palmer, M.A., E. Bernhardt, E. Chornesky, S.L. Collins, A. Dobson, C. Duke, B. Gold, R. Jacobson, S. Kingsland, R. Kranz, M. Mappin, F. Micheli, J. Morse, M. Pace, M. Pascual, S. Palumbi, J. Reichman, W.H. Schlesinger, A. Townsend, M. Turner & M. Vasquez. 2004. Ecology for a crowded planet. Science 304:1251-1252

Redman, C.L., J.M. Grove & L.H. Kuby. 2004. Integrating social science into the long-term ecological research (LTER) network: social dimensions of ecological change and ecological dimensions of social change. Ecosystems 7:161-171.

Singh, N.J. & S. Bagchi. 2013. Applied ecology in India: scope of science and policy to meet contemporary environmental and socio-ecological challenges. Journal of Applied Ecology 50:4-14.

Sukumar, R., H.S. Dattaraja, H.S. Suresh, J. Radhakrishnan, R. Vasudeva, S. Nirmala & N.V. Joshi. 1992. Long term monitoring of vegetation in a tropical deciduous forest in Mudumalai, southern India. Current Science, 62: 608-616.