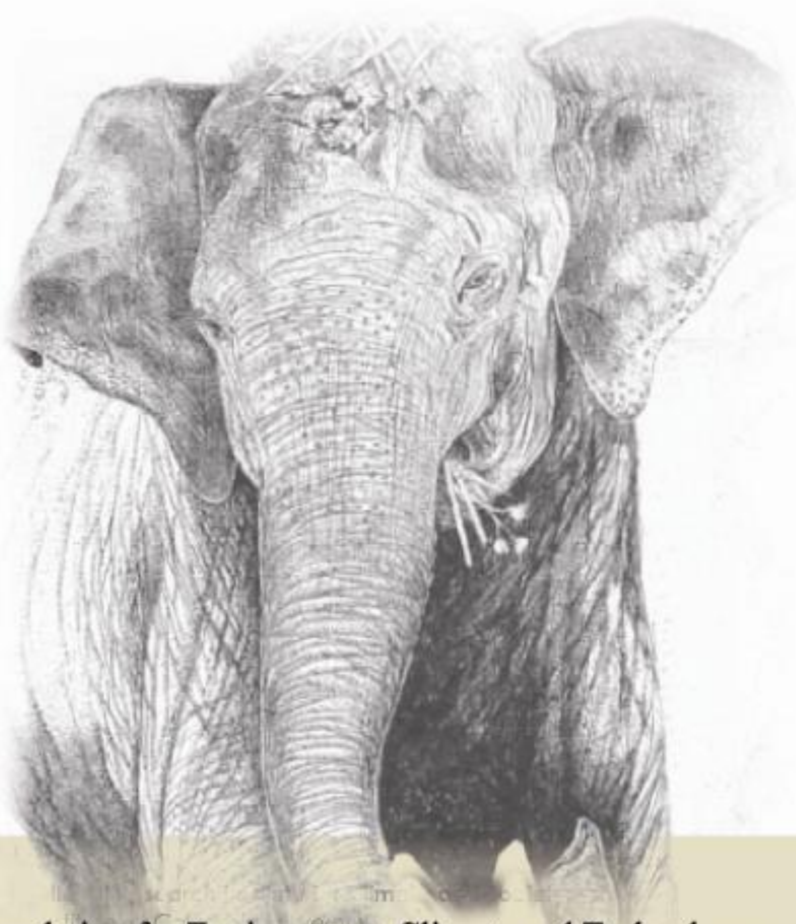
Evaluation of Climate and Habitat Interactions Affecting the Conservation and Management of Asian Elephants in Southeast Sri Lanka



Foundation for Environment, Climate and Technology
SRI LANKA

Contact:
Principal Investigator:
Lareef Zubair,
Foundation for Environment, Climate and Technology,
C/o Maintenance Office, Mahaweli Authority of Sri Lanka,
Digana Village, Rajawella, Sri Lanka
Tel: +94-81-2376746
lareefzubair@gmail.com

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Table of Contents

Executive Summary

Contemporary ecological research indicates the need to be concerned about the preservation of habitats and the preservation of keystone species that are critical to the ecological character of the habitats. Conservation of endangered species works best with attention not only to the endangered species but also to the needs of the people who may be adjacent to or bordering habitats. Parts of Sri Lanka fall into the category of globally important biodiversity hotspots. The biggest land animal, the elephant is the keystone species in Sri Lanka outside the highlands. The population of elephants in Sri Lanka is estimated to be between 3000 and 4,000; yet there has been an alarming loss of 1000 elephants during 1990-2003. Given its island setting and rich hydro-climatic data, Sri Lanka provides a unique opportunity to study the dynamics leading to species loss.

Our work in this project was initially motivated by the practical concerns of our project partners in the Mahaweli River Basin in Sri Lanka where the human-elephant conflict was becoming a major problem- not only for elephants, but also for people and their livelihoods. The question that arose: "Is the climate, water availability and river basin management a part of the factors that leads to conflict rather than coexistence between elephants and people?" If this was indeed the case, then could one adaptively manage the river basin, organize agricultural practices, and prioritize conflict mitigation options such as separate tanks for drinking water for elephants and habitat enrichment programs on the river basin management side? One could also propose various adaptive measures in changes in wildlife management if one could monitor the climate and environmental conditions and also take advantage of seasonal climate predictions.

Climate

A climatic data set was gathered at a spatial density and historical extent that is unmatched in the tropics. Quality control was undertaken and high-resolution gridded data sets were produced. Spatial interpolation methodologies were developed to obtain improved gridding routines both using commercial GIS software and the data-library. Climatologies were developed for mean, maximum and minimum temperature and for annual rainfall. A downscaling methodology that significantly enhanced skill was developed for the main rainy season from October-December. Outputs from the ECHAM GCM were downscaled to 20 km grid and stations.

Climate and Human-Elephant Conflict

The elephant fatalities data was segregated in multiple ways, and trends of decadal and inter annual variations were identified by region. An analysis of climate influences on fatalities showed a distinct climatic influence when the data were segregated according to the appropriate season. Elephant deaths were significantly correlated with droughts in the early part of the year. This observation was unexpected. Floods in the latter part of the year were correlated with enhanced elephant deaths – a relationship which was not statistically significant. Data over a longer period is needed to disentangle the influences of the drought in the early season with that in the late seasons. This modulation is characteristic of El Nino years in Sri Lanka. These results remained significant and were brought out when decadal scale signals were removed.

This study demonstrates that climate significantly influences the wildlife in conflict in tropics; thereby, wildlife management can benefit from the analysis of climate variability.

Communication of Findings

These findings were presented at the International Research Institute for Climate and Society (IRI), the Lamont Doherty Observatory Open House, the Sri Lanka Department of Wildlife Conservation and the Mahaweli Authority's Environment Division in Sri Lanka in November 2004. Six posters that document aspects of the project were displayed at the Lamont Doherty Earth Institutes Open House in October 2004. The results of the downscaling have been published in two conference reports.

Management of the Project

This project report documents work was done by FECT and the IRI. FECT undertook data acquisition, GIS mapping, documentation, programming and the engagement of a research assistant. A Senior Research Staff Assistant was engaged part-time to work on data library, downscaling, GIS work and hydrological analysis.

Follow-Up Grants

This project benefited from and assisted in the Adaptation and Impact Assessment of Climate Change for Plantation's project. This project's ground work provided us with the information necessary to carry out a high-resolution hazard analysis and a case-study of Disaster Risk for the Earth Institute's Disaster Hotspots Study. The grant proposal for "Climate and Malaria" to the NOAA/NSF consortium depended substantially on the work carried out under this seed grant.

A. Acknowledgements

This project was executed with a seed-grant from the International Research Institute for Climate Prediction We are thankful for their support and careful attention. We thank Michael Bell, Chet Roplewski and Jennifer Phillips at IRI for their team support. Our work benefited from discussions with Drs. Prithiviraj Fernando and Fred Koontz at the Centre for Environmental Research and Conservation and Wildlife Trust.

We thank Mr. S.B. Rajakaruna, Ms. Asoka Amarasekera and Ms. H. M. Renuka of the Natural Resources Management Services for assistance with the management of project work. We gratefully acknowledge contributions from Mr. Heli Bulathsinhala, Ms. Kusalika Ariyaratne, Mr. Irugal Bandara and Mr. Chanaka Wickremasinghe. We thank Madhura Weerasekera, Sanjaya Ratnayake, and Sewwandhi Chandrasekera for helping to finalize this report.

The use of data from the Mahaweli Authority of Sri Lanka, Sri Lanka Department of Irrigation, Sri Lanka Department of Meteorology and the Sri Lanka Department of Wildlife Conservation is gratefully acknowledged.

The information on elephant habitat provided by various officials of the Environment and Forest Conservation Division of the Mahaweli Authority including the Director, Mr. Ranjith Herath and Mr. Mahinda was valuable. We thank the Director of Sri Lanka Department of Wildlife Conservation, Mr. Dayananda Kariyawasam for providing guidance to this work.

Dr. Lareef Zubair (PI)
FECT, C/o Maintenance Office, Mahaweli Authority of Sri Lanka, Digana Village, Rajawella, Sri Lanka
Tel: +94-81-2376746
lareefzubair@gmail.com

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Cover Photo: Elephant in Bundala National Park, Hambantota, South-Eastern Sri Lanka, January 2005, Pix by Lareef Zubair.

B. Project Team

Foundation for Environment, Climate and Technology, Sri Lanka.

Digana Village, Rajawella, Sri Lanka.

Upamala Tennakoon - Mapping Services.

Janaki Chandimala - Downscaling and Data Management.

Zeenas Yahiya - Documentation.

M.R.A. Siraj - Website development and computer support.

Vidhura Ralapanawe - Information Technology and Sustainable Development

Lareef Zubair - Principal Scientist (Principal Investigator)

IRI

International Research Institute for climate prediction, Monell Building, P.O. Box 1000, 61 Route 9W Palisades, New York, NY 10964, USA.

Benno Blumenthal - Data Library Manager (Data Management)

Ousmane Ndiaye - Staff Associate (Downscaling)

Neil Ward - Director, Decision Systems (Downscaling and Project Management)

Ruvini Perera - Senior Research Staff Assistant (Downscaling and Data Management)

Lareef Zubair - Associate Research Scientist (Principal Investigator)

Mahaweli Authority of Sri Lanka

Dam Site, Environment and Forest Conservation Division, Mahaweli Authority of Sri Lanka, Polgolla, Sri Lanka.

Herath Manthrithillake - Director.

1. Introduction

Two major contemporary environmental issues are the alarming loss of biodiversity, and climate change. Both these issues are intertwined in many instances with one perhaps compounding the problems due to the other. It has been argued that biodiversity loss and climate change are related and premature, and not driven by evidence. Quantitative analysis is needed of the relationship between climate and its impacts on endangered species. This is difficult because there is a dearth of long-term data on endangered species at sufficient spatial and temporal resolution to assess the impacts of climate.

Contemporary ecological research indicates the need to be concerned about the preservation of habitats and the preservation of species that are critical to the ecological character of the habitats. Arguably, the conservation of endangered species is only possible with attention to the needs of the people who may be adjacent to or bordering habitats with endangered species.

Parts of Sri Lanka fall into the category of globally important biodiversity hotspots. The biggest land animal in Sri Lanka is the elephant. Except for certain areas in the highlands, the elephants represent the keystone species in Sri Lanka. The population of elephants in Sri Lanka is estimated to be between 3, 000 to 4,000; yet there has been alarming loss of 1000 elephants during the previous decade. Given its island setting, extraordinarily rich environmental data and skillfully predictable climate, Sri Lanka provides a unique opportunity to study the dynamics leading to species loss.

Our work in this project was initially motivated by the concerns of our project partners in the Mahaweli River Basin in Sri Lanka where the human-elephant conflict was a major problem not only for elephants, but also for human security and livelihoods. The question that arises: “Is the climate, water availability and river basin management affecting the conflict between elephants and people?” If this was indeed the case, then could one adaptively manage the river basin, organize agricultural practices, and prioritize conflict mitigation options such as separate tanks for drinking water for elephants, habitat enrichment programs on the river basin management side. One could also propose various adaptive measures in changes in wildlife and natural resources policy.

1.1 Elephants in Sri Lanka

The future of the global populations of the endangered Asian elephant (*Elephas maximus*) is uncertain. This is partly due to the fact that their populations have been relegated to small and relatively isolated pockets throughout their historic range in southern and southeastern Asia. In Sri Lanka, their numbers have dwindled from 8,000 to some 3,000-4,000 individuals. If these populations are to survive, in the face of mounting habitat loss and human resource competition, it is necessary to develop a set of research strategies and management methodologies aimed at effectively and actively managing their habitats as well as genetic and demographic dynamics.

Understanding how interactions between climate and habitat can affect elephant ecology will be important for the long-term conservation and management of the species. When extreme conditions occur, wildlife can become increasingly vulnerable to normally marginal effects such as climate variability and resource condition change. The need for more sophisticated techniques informing elephant management in human/wildlife landscape mosaics is clearly evident today in Sri Lanka.

Sri Lanka, an island roughly 25,300 sq. mi., carries a human population (19.2 million, 2000 estimate) and a wild elephant population of around 3000-4000 individuals. While some 10-15% of the island's land area has come under conservation status (National parks and reserves), these protected zones account only for approximately one third of the elephants natural ranges. A main approach to elephant conservation in Sri Lanka, as in much of the rest of Asia, has been to attempt to restrict elephants to conservation areas. However, in the face of the intense drought impacts plaguing the region these past years, conservation areas alone necessarily limited in size and composition are facing great difficulty sustaining large populations of mega-herbivores such as the elephant. Indeed artificially maintaining high elephant densities in conservation areas by translocation has caused major disturbances to those very reserves. The well-being of elephant populations in such areas are, and will become increasingly dependent on the ability of wildlife managers to understand the dynamics that lead to human-elephant conflict or harmony and manage conservation and adjoining areas to mitigate conflict.

1.2 Climate, Habitats and Elephant Ecology

We explored the relationships between climate, habitat, and elephant ecology in Sri Lanka to provide elephant managers with information and spatial methodologies that aim at improving both short-term and long-term elephant conservation management. We developed a set of textual and geospatial databases and conducted an analysis of the relationship between climate and conflict. Methodology for fine scale seasonal climate predictions was adapted and developed. These are the first steps in building a more sophisticated systems model for assessing increasingly long-term scenarios of the responses of habitat and elephant ecology to seasonal climate forecasts, first within the study area and potentially across a broader range of the Asian elephant. The project we believe is a pioneering example of how climate knowledge can be integrated into wildlife management strategies.

The main limiting factors for elephants in Sri Lanka are the availability of fodder and surface water. These resources assume much greater significance than usual when elephants are restricted to conservation areas and are prevented from tracking changing resources. Human and elephant conflicts increase around such zones in the face of intensified resource competition. The assessment of climate's seasonal variability and impact on habitat conditions may allow remedial action to be taken that could pre-empt or mitigate crisis situations. For instance, over most of its range in Sri Lanka, dry seasons limit the elephant's access to water and fodder; availability increases during the rainy season (October to January). If, through assessing short-term seasonal climate outlooks (such as associated with El Nino), rainfall is expected to be below average in a given year, a greater effort can be expended in activities that will address shortfalls in the coming term. For example, additional surface water can be collected by modifying water holes and reservoir systems, and strategies such as habitat modification can be adopted to increase browse availability within reserves. If the rains are projected to fail entirely, plans can be made to provide water and fodder artificially. While such management interventions would promote the conservation of elephants and other fauna in protected areas, they would also mitigate human-elephant conflict. The presence of sufficient resources for elephants within conservation areas can stem the likelihood of their preferentially moving into human dominated areas.

Our objective was to generate and make available integrated climate, biophysical, ecological pattern and process study results that can have decision support applications for natural resource managers and policy decision makers within the region.

We have shown in other work that seasonal rainfall variability is meaningfully linked to drought dynamics. We have also shown through this work that seasonal climate predictions are skillful particularly for the areas inhabited by elephants. Thus seasonal climate monitoring and seasonal predictions can be used to inform appropriate management interventions to prevent or mitigate crises. Such interpolative capabilities could have important management implications in focusing asset utilization, budget prioritization (e.g. deployment of specialized personnel) and further research efforts.

Our project pioneers the investigation of climate impacts on a wildlife species with important keystone ecological functions and cultural significance. Wildlife scientists and conservationists in general are becoming increasingly aware of the importance of considering the effects of climate in both short and long-term planning and management strategies. However, the field has yet to systematically incorporate climate variability or adopt climate forecasting as de rigueur in most conservation assessments.

1.3 Activities Carried Out

The work undertaken may be categorized as below:

Climate and Hydrological Component:

- A climatic data set was gathered at a spatial density and historical extent that is unmatched in the tropics.
- Hydrological data and vegetation data were gathered.
- Quality control was undertaken and high-resolution gridded data sets were produced.
- Spatial interpolation methodologies were developed to obtain improved gridding routines both using commercial Geographic Information System (GIS) software and the data-library.
- Climatologies were developed for mean, maximum and minimum temperature and for annual rainfall.

- A downscaling methodology that significantly enhanced skill was developed for the main rainy season from October-December. Outputs from the ECHAM GCM were downscaled to 20 km grid and stations.
- Several researchers (Ruvini Perera, Upamala Tennakoon, Heli Bulathsinhala and Janaki Chandimala) obtained competence in climatic data analysis.

Environmental Data Analysis:

- Benno Blumenthal helped incorporate the historical Normalized Difference Vegetation Index (NDVI) data at 20 km into the data library. Climatologies were produced with this data set.
- Seasonal cycle of NDVI was documented.

Human Elephant Conflict:

- Background research was undertaken by the PI and Zeenas Yahiya of Natural Resources Management Services (NRMS) on elephants in Sri Lanka
- Zeenas Yahiya obtained a 14 year time series of elephant deaths from the Sri Lanka Department of Wildlife Conservation.
- This data set was segregated in multiple ways and trends of decadal and inter annual variations were identified by region by Zeenas Yahiya

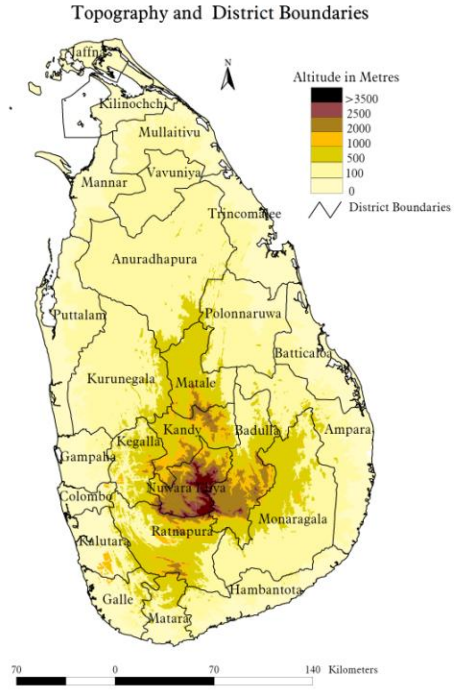
Climate Impacts on Human Elephant Conflict:

- An analysis of climate influences on Human Elephant Conflict was undertaken by the PI with Janaki Chandimala of the NRMS. This analysis showed a distinct climatic influence when the appropriate season was considered.
- Elephant deaths were significantly correlated with droughts in the early part of the year. This observation was unexpected.
- Floods in the latter part of the year led to enhanced elephant deaths. This relationship is not statistically significant. Data over more time periods is needed to disentangle the influences of the drought in the early season with that in the late seasons. This modulation is characteristic of El Nino years in Sri Lanka.
- These results remained significant and were brought out when decadal scale signals were removed.

2. Project Region

2.1 Topography

Sri Lanka is an island of 65,000 square kilometers. The principal topographic feature is an anchor shaped mountain massif in the South-Central part of the island (map 1). The topography and differences in regional climate are underlying causes of the contrasts in many facets of the island.



Map 1: Topography and District Boundaries of Sri Lanka

2.2 Population

55% of the population is concentrated in 20% of the land area, with 30% of the population estimated to be in urban areas. The least populated districts have 10% of the population spread out in 40% of the land.

2.3 Agriculture

The primary food crop is paddy; its cultivation is undertaken as subsistence farming. In addition, coconut and spices are major food crops. Major "cash-crops" include tea and rubber.

Our previous work has shown a correlation between rainfall variations and agricultural production. The agrarian economy is susceptible to disruption through drought, floods and anomalous variability in climate. The island has a vast network of rivers, reservoirs and canals that is used to manage the impact of both spatial and seasonal climatic variability.

2.6 Key Statistics

Table 1: Key Statistics of Sri Lanka

Location	South Asian island in Indian Ocean
Geographic Co-ordinates	Between 6o-10^{o}N and 79^o – 82^{o}E
Area	Total: 65610 km^2 Water: 870 km^2 Land: 64740 km^2
Coastline	1340 km
Elevation extremes	Lowest point: 0 m Highest point: 2524 m
Population	19,742,439 (2003)
Languages Spoken	Sinhala (74%), Tamil (18%), English (10%)
Export commodities	Textiles and apparels, tea, diamonds, coconut, petroleum products
Literacy	92.3%
Life Expectancy	72 years
Population below poverty line	22% (1997)
Unemployment rate	8%
Human Development Index Rank	99 out of 175
Budget	Revenues $2.8 bill. Expenditure $4.1 bill.
External Debt	$9.8 billion (2002)
GDP	$15.7 billion (2001)
GDP per capita	$ 823 (2001)
GDP by sector	Agriculture :20% Industry: 26% Services: 54%

3. Climatological Description

Given its size Sri Lanka shows a remarkable variation of topography and climate among its regions. The variation in temperature is modest with the mean value being 27 ^{0} C with a mean daily range of 6^{o} C. The relative humidity varies from 60% to 90%. Westerly winds prevail over the island from May to September and North-Easterly winds prevail from December till February. The seasonal and regional variation of rainfall is remarkable and it shapes much of the biophysical landscape of the island.

The significant climatic processes that bring rainfall to Sri Lanka are Inter-Tropical Zone {April to June (AMJ) and October to November (ON)}, Easterly Jet mechanism {July to August (JA)}, the monsoon {October to December (OND)} and orographic rainfall on the Western hill slopes {May to September (MJJAS)} and on the Eastern hill slopes {December to February (DJF)}. The traditional agricultural calendar suggests of *Yala* (April to September) and *Maha* (October to March) suggest a natural 3-month interval for seasons (AMJ, JAS, OND and JFM) that demarcates approximately the cultivation and harvest phase of the seasons (figure 1).

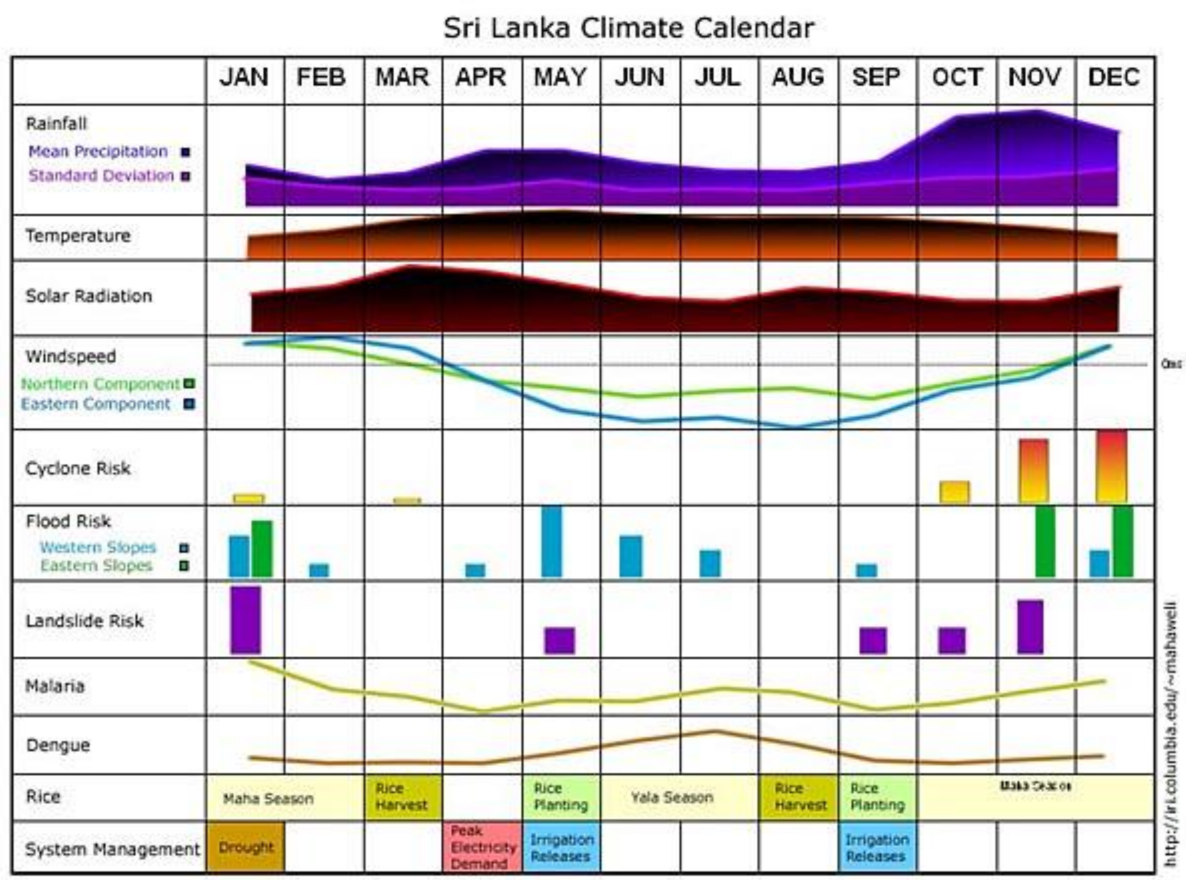
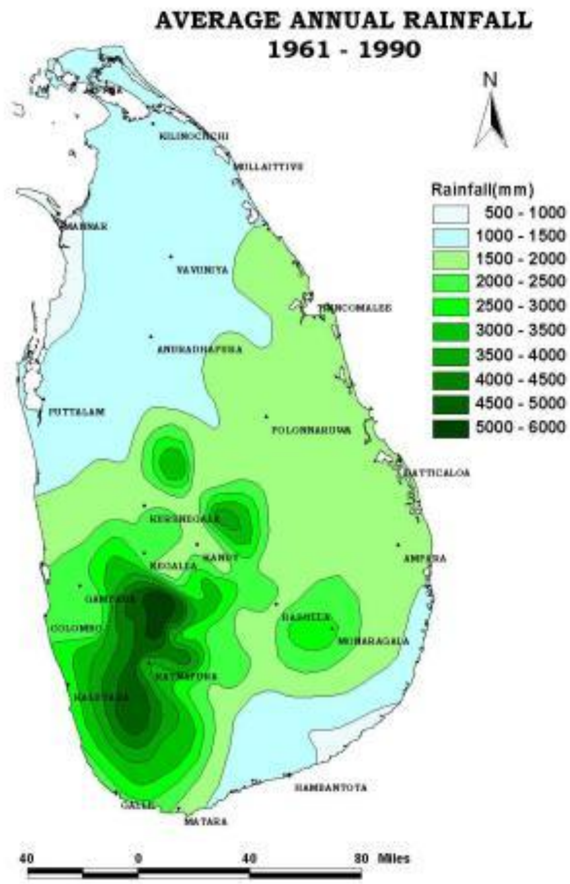


Figure 1: The monthly variation of mean precipitation, variability of precipitation, temperature, solar radiation, wind vectors, hazards, epidemic risk and water management

3.1 Rainfall Climatology

Rainfall data for 179 stations (shown in figure 2) were obtained for the period from 1961 to 1990 as shown in map 2. Seasonal variation of rainfall was constructed (figure 3). The data were subject to quality control in order to identify the suspicious data and stations. Interpolation used the Inverse-Distance-Weighing method.



Map 2: Average Annual rainfall variation in Sri Lanka

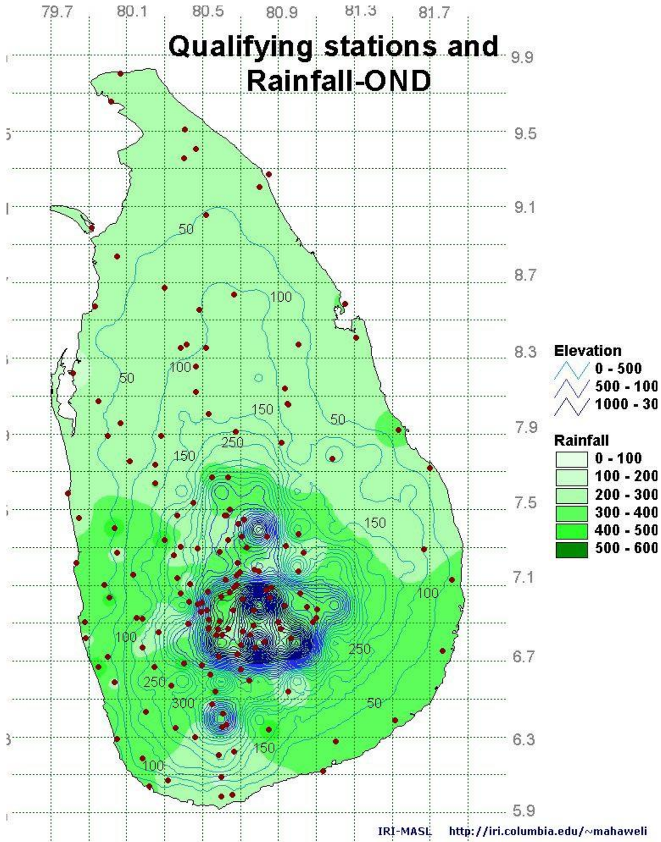


Figure 2: The 98 rainfall stations that were used in this analysis. The topography is shown as contours. In addition, the shading shows the climatological rainfall from October to December. Generally, the rainfall is fairly evenly high throughout Sri Lanka in comparison with other seasons.

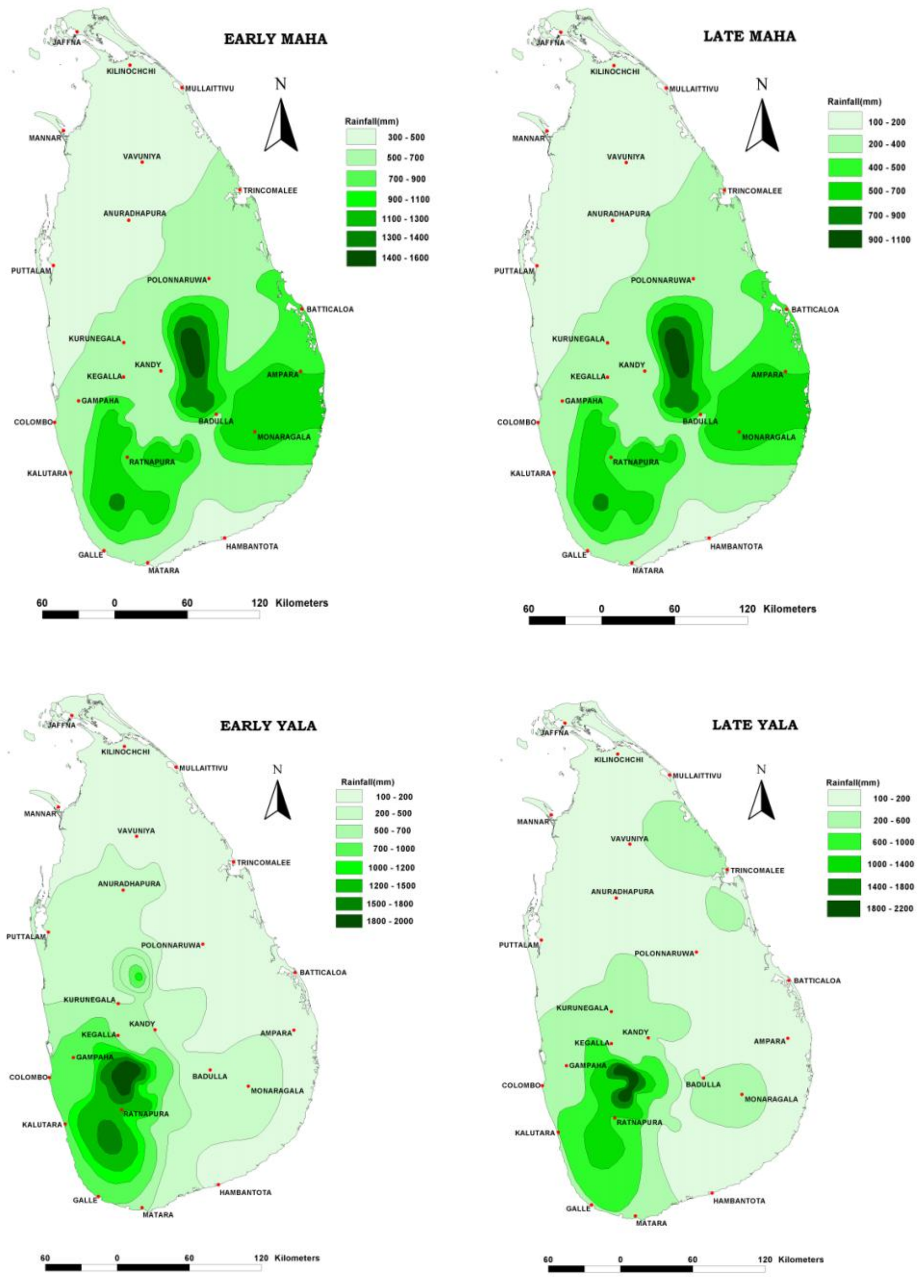
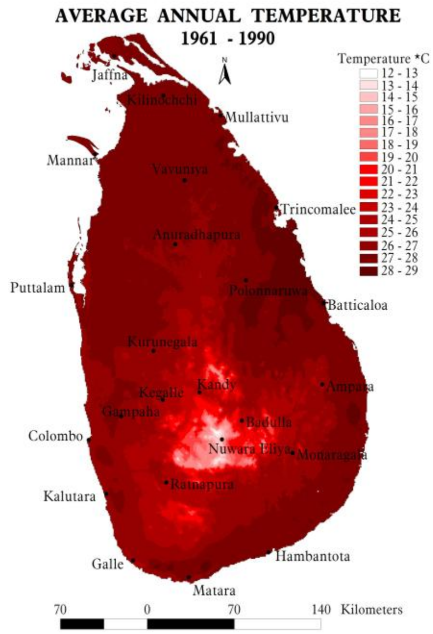


Figure 3: Average seasonal rainfall (clockwise starting at top left) Oct-Dec, Jan-Mar, Apr-Jun, Jul-Sep..

3.2 Temperature Climatology

Temperature data for Sri Lanka are available in 18 Sri Lanka Meteorology Department stations and 19 Sri Lanka Agriculture Department stations for more than 100 years. These data are available separately for maximum temperature, minimum temperature and mean temperature in annual and monthly bases. Map 3 shows the average annual temperature for the period from 1961 to 1990. The seasonal and regional distributions of temperatures are shown in the figure 4.



Map 3: Regional variation of mean temperature in Sri Lanka

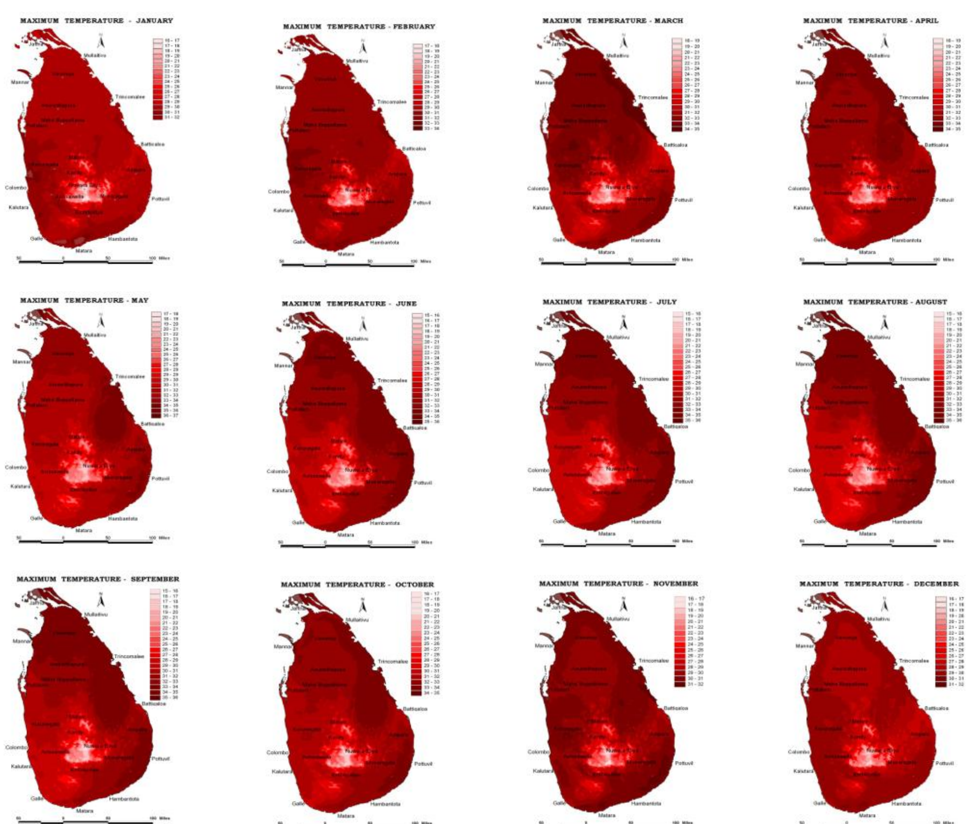


Figure 3: Monthly climatologies for maximum temperature in Sri Lanka

3.4 NDVI Seasonality for Sri Lanka

Normalized Difference Vegetation Indices for a twenty year record were introduced into the data library prompted by the project needs. Figure 4 describes the monthly climatology of NDVI. The seasonal variation is in keeping with what is expected based on rainfall. During the summer months (June-September) there is a decline in NDVI throughout the island. By October this deficit begins to change particularly in the areas of contemporary elephant habitats. Thus it appears that fodder availability shall be particularly stressed during the period until October.

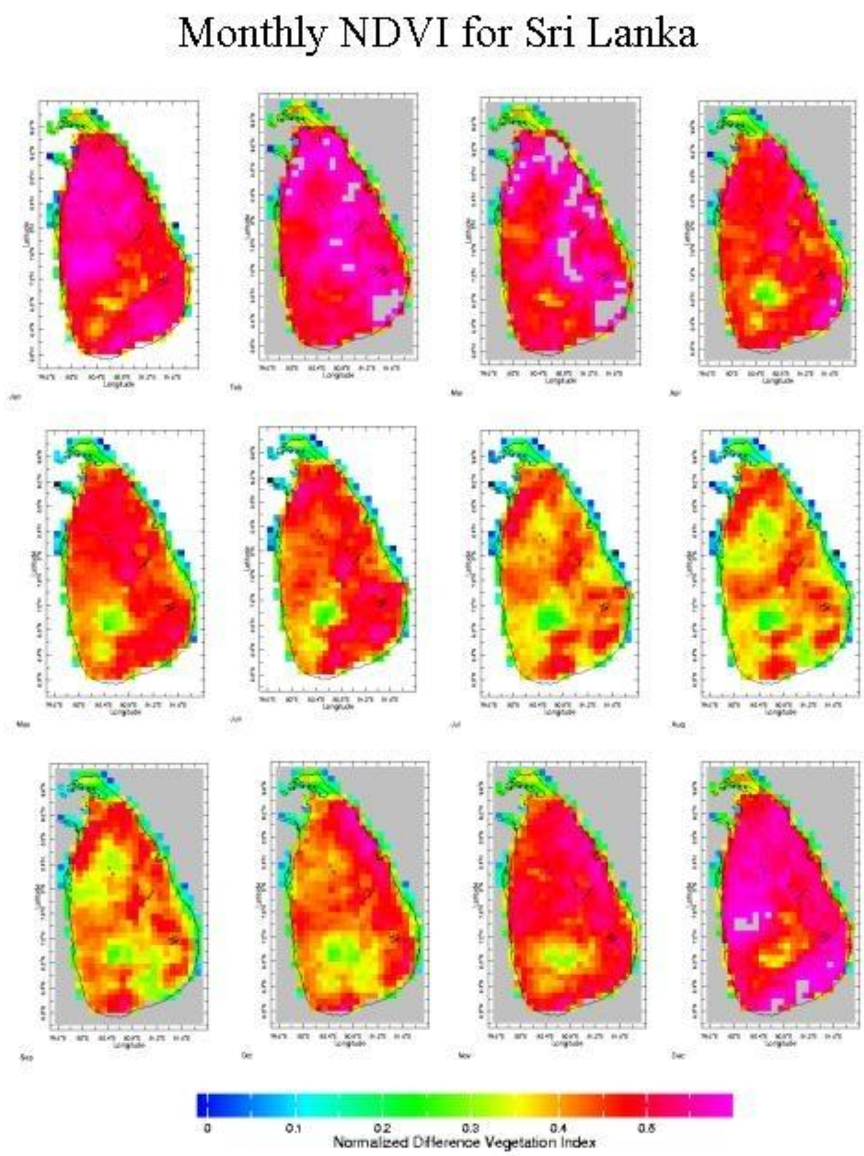


Figure 4: Monthly NDVI for Sri Lanka.

4. Fine-Scale Prediction of Rainfall

4.1 Introduction

Sri Lanka receives 45-70% of its rainfall between October and December at the start of the main Maha cultivation season. It has been known for sometime that the El Niño/Southern Oscillation (ENSO) phenomenon and associated large scale modulation by the Walker circulation modulates the Maha rainfall. Recent work has shown that the Indian Ocean Dipole (IOD) mode modulates the Maha rainfall due to a local Walker-type circulation system in the tropical Indian Ocean. Thus there is a physical basis as to why the large-scale atmospheric circulation across the Indian Ocean sector is likely to have a strong degree of predictability in the October-December season. Predictions with Global Climate Models (GCMs) however are at a resolution of 250 km that is too coarse for practical use in Sri Lanka. The topography changes drastically over small distances in Sri Lanka and downscaling requires high-resolution to be able to obtain useful fine-scale results. We have attempted to develop "downscaled" rainfall predictions for Sri Lanka at a resolution of 20-km grid.

We ask the question: for a given large-scale wind forecast across the region, what are the details of the rainfall pattern to expect across Sri Lanka? Two ways to answer this question are

1. Run a high-resolution climate model driven with the large-scale wind fields from the Global Climate Model. Indeed such an effort is already underway (Qian and Zubair, 2004).
2. Establish the statistical relationship between the details of the observed rainfall pattern and the large-scale wind forecast using analysis over a large set of past years and use these relationships to forecast each location in Sri Lanka, given a large-scale wind forecast.

The second approach has the problem that the details of the relationships are vulnerable to sampling error, and we may introduce details into the forecasts that have no physical basis. However, they can be used to give a first indication of predictability, especially when they are interpreted using knowledge of the physical climate system. Here, we take the second approach and report on statistical downscaling for Sri Lanka for October to December period using GCM output.

4.2 Methods

The downscaling was based on the relations between 30 years of ECHAM5.4 Global Climate Model output with observations on the ground. The fundamental principle of statistical downscaling is the use of multivariate regression between model fields and observed anomalies. Principal Component Analysis (PCA) of model fields and observations reduces the number of degrees of freedom and decreases the effects of sampling error. Canonical correlations analysis (CCA) is used to identify model fields that are most highly correlated with observed precipitation patterns. The set of CCA correspondences between model and observation patterns is then used to predict observed precipitation anomalies from model outputs.

The downscaling proceeded in the following principal steps:

- Using the October-December station rainfall totals, create a dataset of October-December rainfall values for each season 1950-1980, on a 20km x 20km grid across island.
- Extract leading indices of the forecast near-surface wind circulation across the region, by analyzing each forecast made by the Global Climate Model, 1950-1980. We use the leading Principal Components of the low-level zonal circulation.
- Calculate the regression relationship between the circulation index forecast by the model, and the rainfall observed at each grid-box across Sri Lanka
- Use the relationships to make a forecast for each grid-box in each October-December season 1950-1980. We make our forecasts in a cross-validation mode.
- Evaluate the accuracy of the predictions for each grid-box.

4.3 Results

During wet Maha seasons in Sri Lanka, the low-level wind field over Sri Lanka and the tropical Indian Ocean is likely to have Easterly anomalies as compared with during the dry season (Figure 5). This observational finding providing further support to the use of the predictions of low-level wind fields from GCM's as a predictor for the Maha rainfall. The observed and downscaled rainfall over a typical grid cell is shown in figure 6. While there are marked differences between the two in terms of amplitude, there is clear correlation between the two time series. The predictions for all grid points over Sri Lanka for a randomly selected year (1950) is shown in figure 7 providing a sense of spatial goodness of predictions. Here, too with some minor variations, there is good correlation between observed and predicted. We have estimated the skill of the prediction from 1950 to 1980 point by point (figure 8). The figure 8 shows significant skill in prediction over Sri Lanka and regional variation in the skill.

The downscaled predictions are consistent with the reported mechanisms; it suggests that the anomalous zonal wind associated with the IOD brings preferential skill to the eastern (windward) side of Sri Lanka. Such downscaling can be extended to other variables including temperature, stream flow and vegetation.

4.4 References

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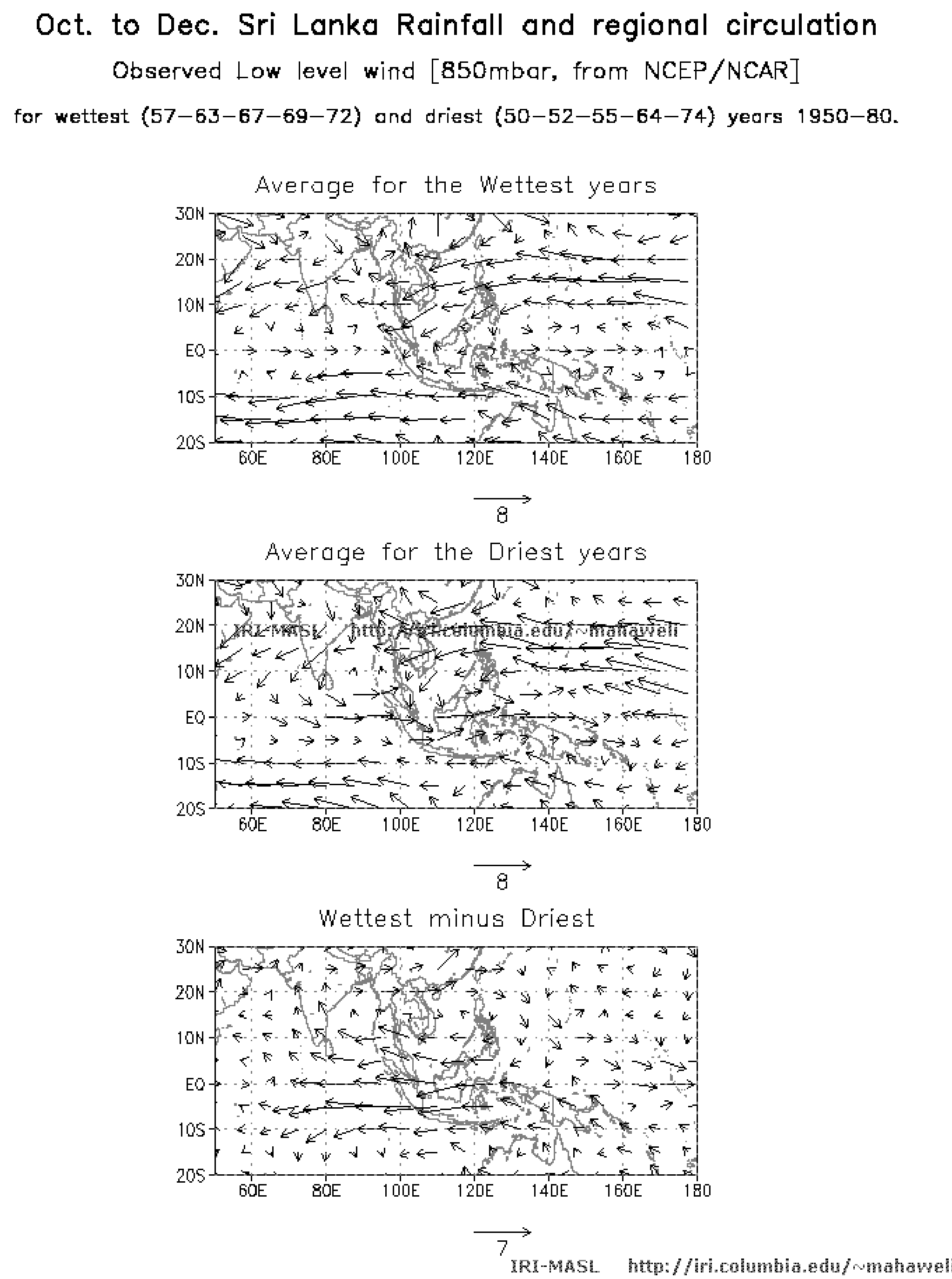


Figure 5: The OND Regional Circulation during Wettest and Driest Years. Here, the years that had wettest Maha's in the period and the driest Maha's were identified. Thereafter composites were made of the regional wind fields from NCEP reanalysis data. Thereafter, the difference fields were estimated.

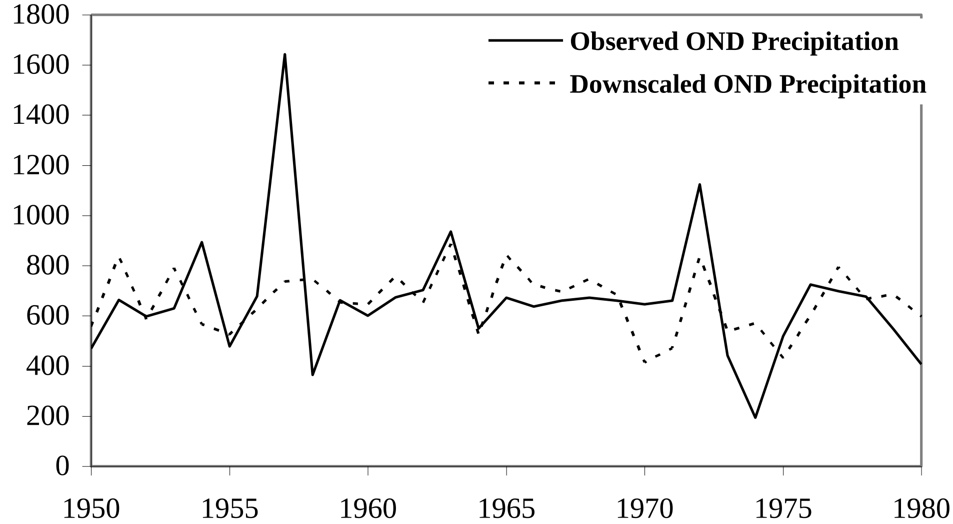


Figure 6: The OND precipitation from the downscaling procedure (dotted line) and the estimate from observations (solid line) are shown for a grid point (82.3°E 6.3°N) as an example. The Pearson correlation of 0.38 is significant at the 95% confidence level.

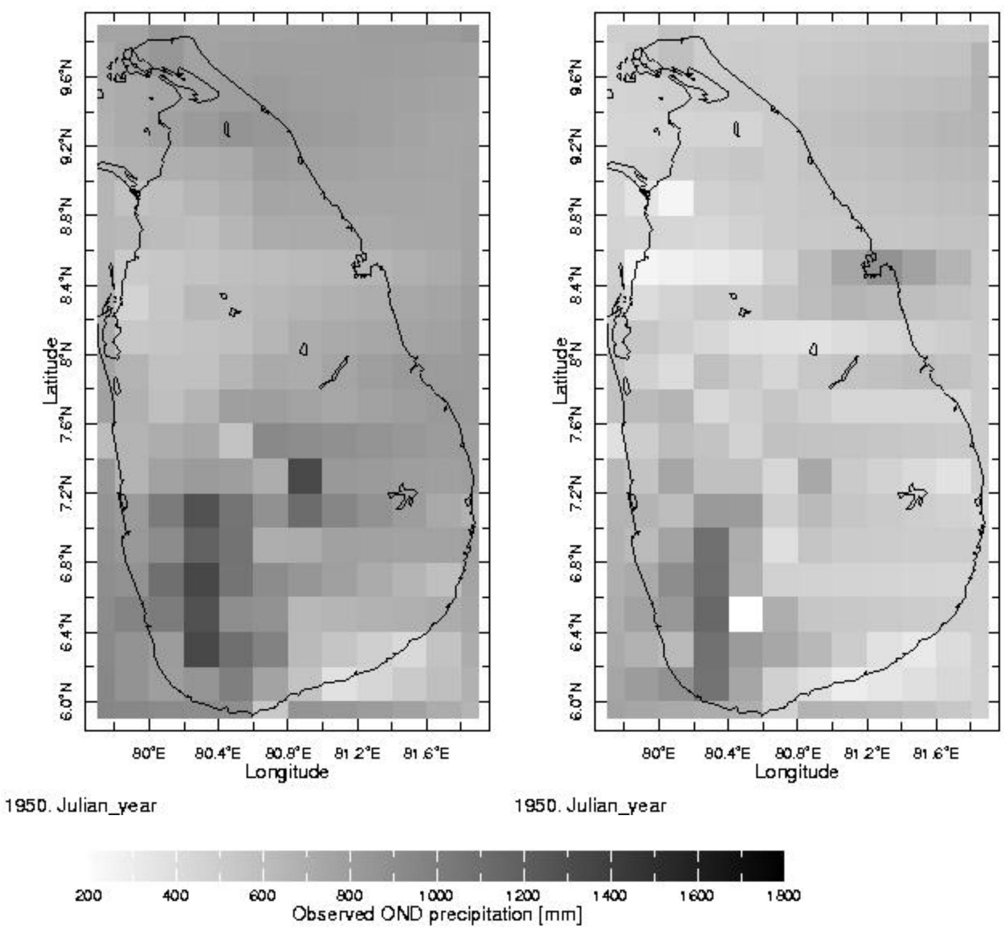


Figure 7: The spatial patterns of precipitation from downscaling from GCM's and estimates of the precipitation from observed data are shown for 1950 as an example.

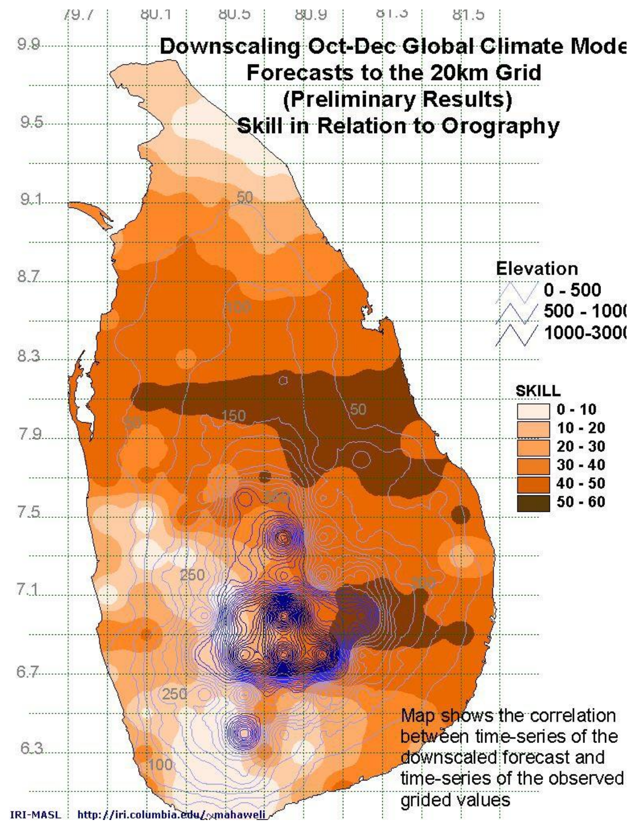


Figure 8: The skill of the predictions was estimated as a temporal correlation (Pearson) for each point. The resulting correlations are shown in shading. High correlations are seen showing skillful prediction. There is regional variation in skill with increasing skill over the Eastern Hill Slopes. The topography values are shown as contour levels.

5. Elephants in Sri Lanka

5.1 Introduction

Asian elephants numbering about 40,000 are an endangered species; 3,000 to 4,000 of these elephants are in Sri Lanka. Population pressures on elephant habitat endanger elephants and rural communities. This conflict is at the heart of environmental conflict, regulation and protection in rural areas. Both human and elephant behavior in the conflict zone are affected by the climate. Climate affects water availability, vegetation, agricultural practices and irrigation. All of these factors could under conditions (such as drought, certain patterns of irrigation or agriculture) lead to competition and conflict.

Table 2: The Number of elephants killed each year

Year	Number of elephant deaths
1990	49
1991	59
1992	90
1993	103
1994	113
1995	94
1996	130
1997	164
1998	148
1999	107
2000	150
2001	162
Total	**1369**

Source: Department of Wildlife Conservation, Sri Lanka

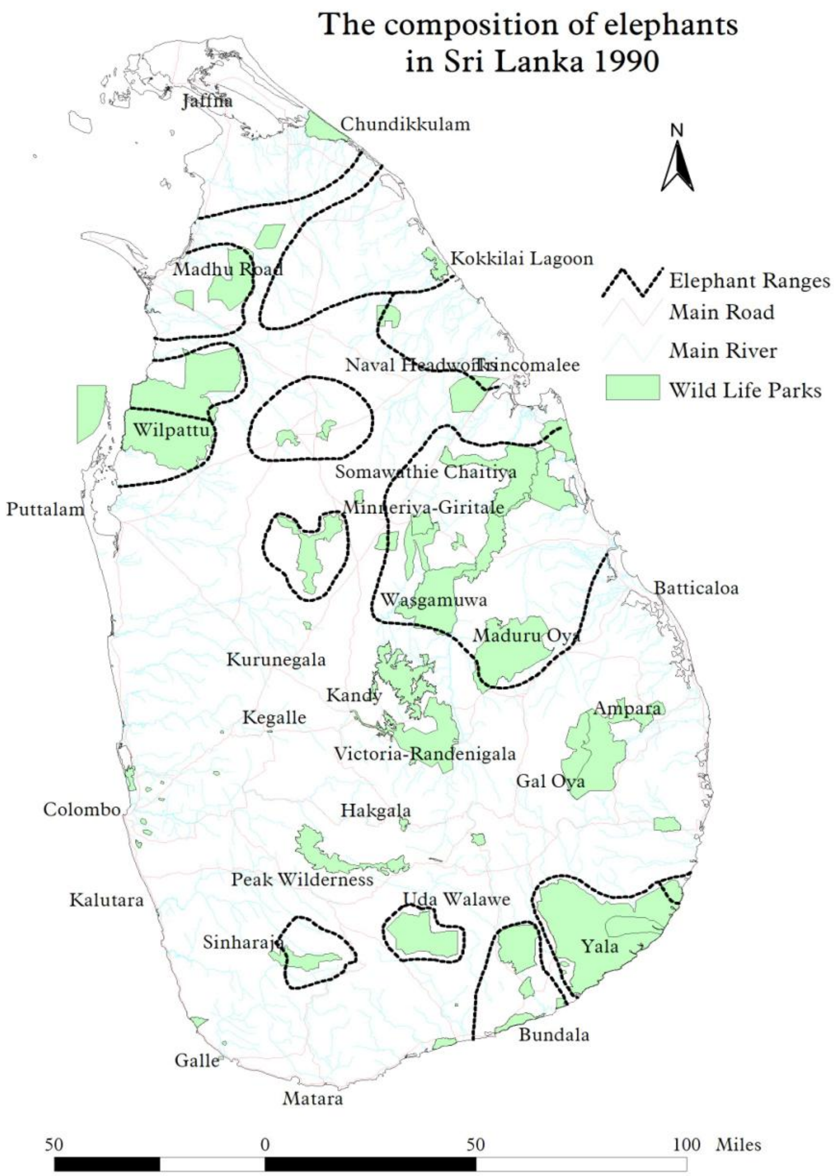
Table 2 indicates that the elephant population will not last in Sri Lanka for more than a few decades unless management is improved.

The sustainable coexistence of humans and elephants depends on:

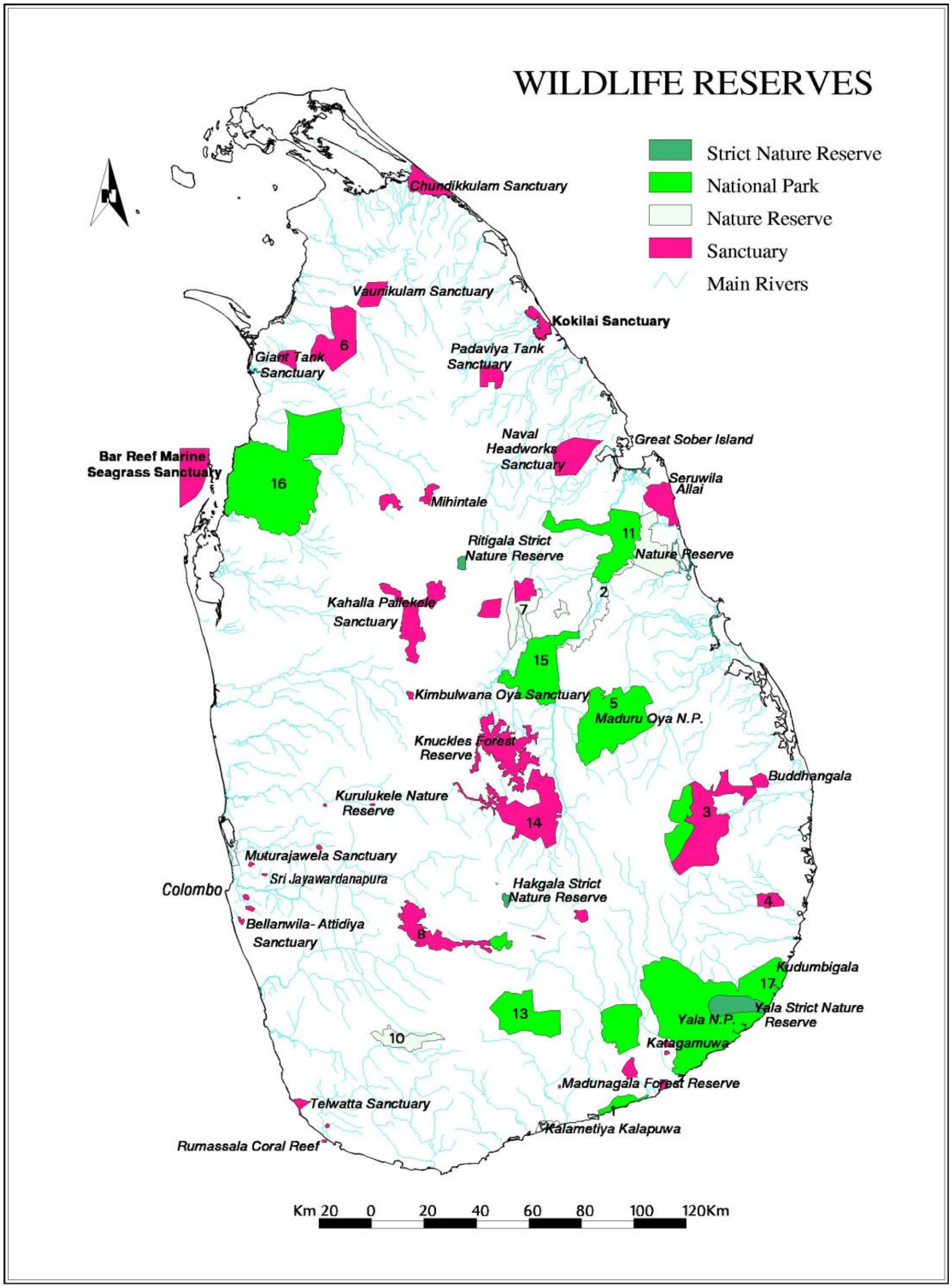
- The maintenance of elephant population in numbers that ensure their genetic viability and resilience to occasional shocks
- The preservation of the habitat of elephants (map 4) including the proper management of dual-use or non-conservation areas. Map 5 shows the existing wildlife reserves available in Sri Lanka.

- The development of human societies in the peripheral areas so as to support their coexistence with the elephant populations (map 6) and the minimization of human-elephant conflict.
- The management of longer term trends in demographics, environment, climate and land use.

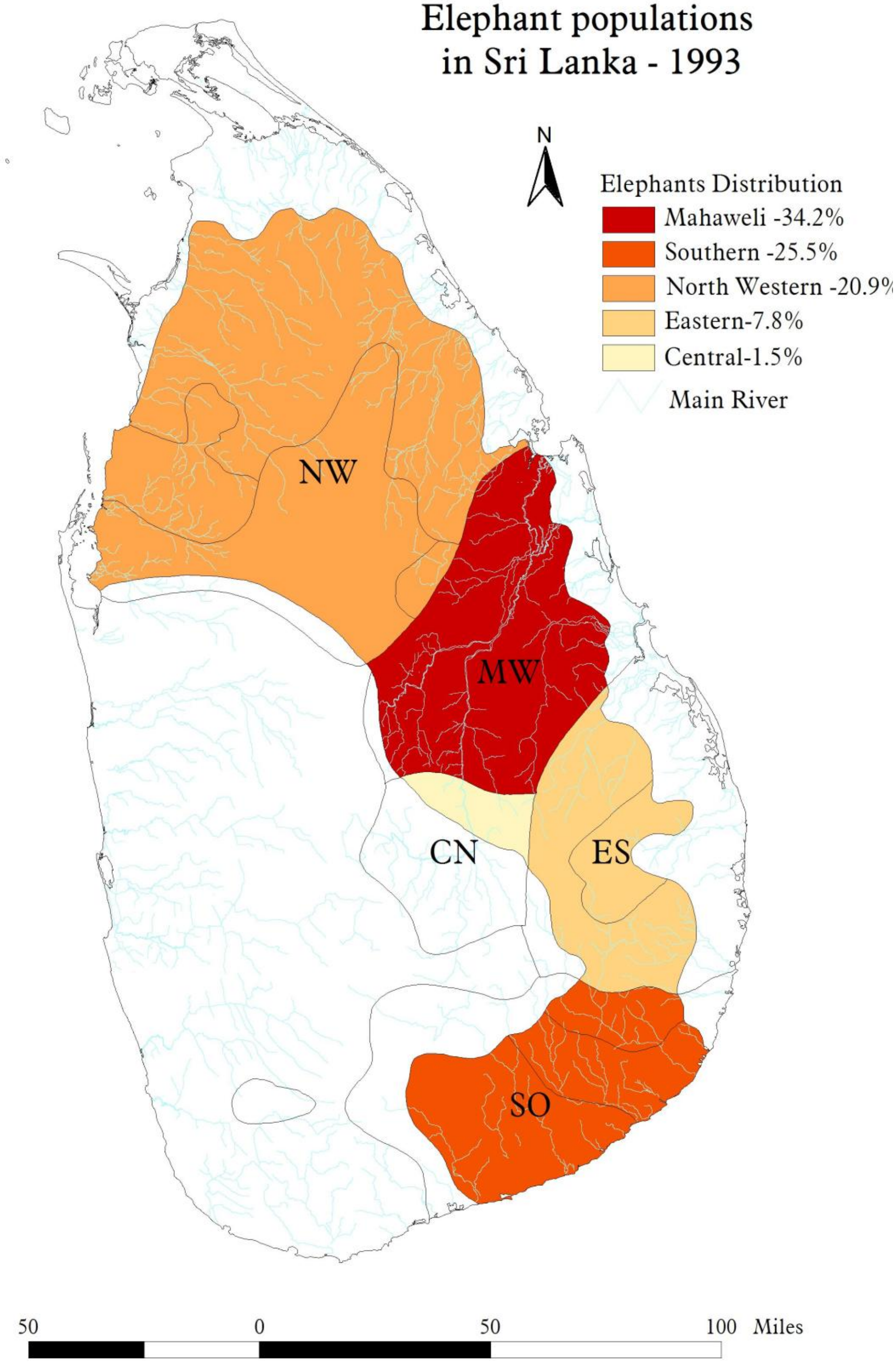
These issues will be discussed in depth after describing the background of elephants, humans, their habitats and the government policies that pertain to land use.



Map 4: The distribution of the elephants in different regions.



Map 5: Wildlife Reserves in Sri Lanka



Map 6: Elephants in the five zones of the Sri Lanka Wildlife Conservation Dept.

Physiology of elephants
An average male adult Sri Lankan elephant may reach 3.5 meters (11 feet 6 inches) in shoulder height and weighs 5,500 kilograms (12,125 pounds). Females are much smaller.

All elephant species have one of the longest gestation periods in the animal kingdom, of 18-20 months. One calf is usually born per gestation period, weighing about 75 - 115 kilograms (165 - 225 pounds) and measures approximately 100 centimeters (3 feet 3 inches) at the shoulder. Elephants reach sexual maturity between the ages of 8 and 14 years, but this varies with the prevailing conditions of the habitat. For instance, during severe periods of drought, puberty may be delayed even up to age of 14-15 years. A female elephant can give birth every 4 - 6 years, and has the potential of giving birth to about 6-7 offspring in her lifetime, which is about 55- 60 years.

The elephant has a very inefficient digestive system: 45% of its food intake is passed through as undigested matter. As a result, the elephant spends most of its life eating and seeking out a continuous and abundant supply of food and water. The elephant's diet is strictly herbivorous. Most elephants consume 100 - 150 kilograms (220 - 330 pounds) of food and 80 - 160 liters (20 - 40 gallons) of water per day. The Asian elephant is adapted to be being a grazer rather than a browser. Its diet includes different types of grasses, as well as juicy leaves and fruits.

Currently, elephants are primarily restricted to the dry zone. The total number of elephants inhabiting Sri Lanka has been estimated various from about 2,000 to around 6,000 (Hoffman, 1978). The Department of Wildlife Conservation estimated the total at 2,500.

5.2 Elephant Population Dynamics

At the beginning of the nineteenth century, there was an estimated 12,000 elephants in Sri Lanka (McKay, 1973). At that time, elephants were found in the dry zone as well as the wet zone and at highest elevations of Horton Plains (Phillips 1980). In the 1850's, the British Colonial Government paid rewards for the destruction of 5,500 elephants (Tennent, 1859). During this period of decline, sport figured as the one of the major reasons for the killing of elephants. Major Rogers, a mid-nineteenth century sportsman, holds the record of having killed 1,100 elephants (Storey 1907). More recently however, crop protection has become the chief cause of killing of elephants. Between 1952 and 1957, 239 of the 475 known elephant deaths occurred during the defense of crops (Sessional Paper No. 19, 1959).

5.6 References

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6. The Role of Climate in the Human-Elephant Conflict in Sri Lanka

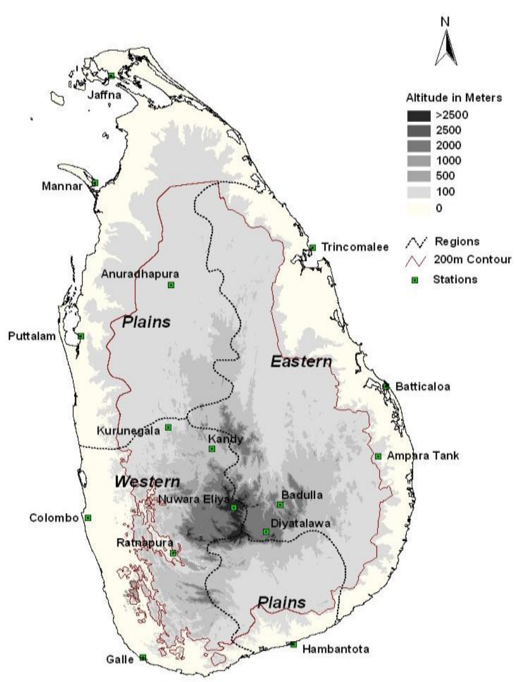
6.1 Introduction

The elephant is the largest land animal in Sri Lanka and 3000-4,000 elephants share Sri Lanka with 20 million people. There has been over centuries a conservation ethic that posits coexistence between humans and elephants. However, increased conflicts in the last 14 years have led to the deaths of 1595 elephants and 600 people. Causes for the conflicts between people and wildlife are competitive stresses on land, water and food, ill-advised or non-existent land use policies, and the consequences of conflict particularly civil wars.

While these are major causes for elephant deaths, climate could also influence the conflict through its modulation of drought, floods, vegetation patterns, irrigation and water management, agricultural cultivation in marginal lands. Here, we explicitly explore this linkage with data on elephant deaths from 1990-2003 on a monthly basis and more extensive climate data in Sri Lanka.

6.2 Data

Sri Lanka rainfall data was obtained from the Sri Lanka Department of Meteorology and the Sri Lanka National Museum library. We used data of 155 rainfall stations from 1869 to the present to construct time series of regional rainfall (map 7).



Map 7: Topography, location of meteorological observatories, and regionalization for Sri Lanka is shown. The 200 m contour that separates the low areas from the hilly areas is shown in red.

Elephants deaths from 1990-2003 by month aggregated for the entire island, annual elephant deaths for the same period by region and by gender were provided by the Sri Lanka Department of Wildlife Conservation to NRMS.

6.3 Analysis

6.3.1 Elephant Death Characteristics

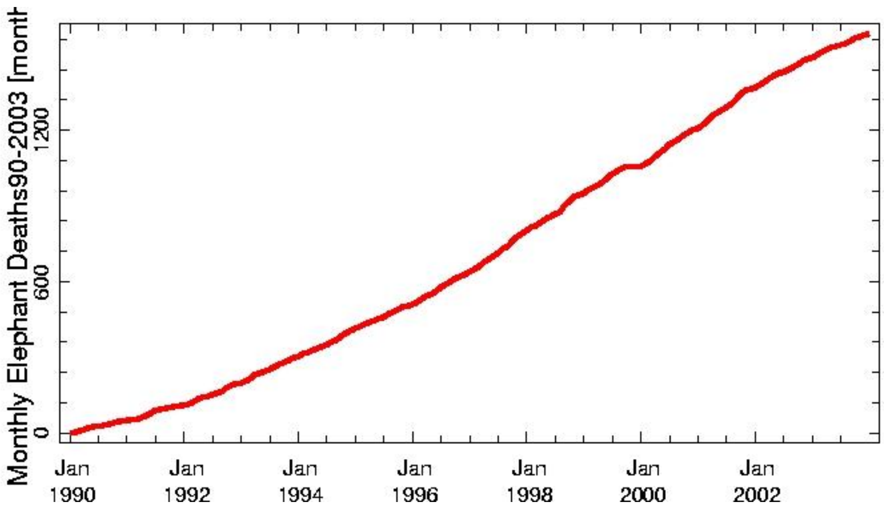


Figure 9: Cumulative losses in Elephants in Sri Lanka (1990-2003)

The number of elephants in Sri Lanka has been estimated in the range of 3000-4,000 (Santiapillai, et al). The cumulative losses in elephants since 1990 (figure 9), the cumulative drop is to be offset by natural increase which are not quantified however, given the large proportion that are killed by gunshot and electrocution (82% of known elephant deaths and 63% of total), the population of elephants is diminishing at a rate that may drive the species to extinction (figure 10.)

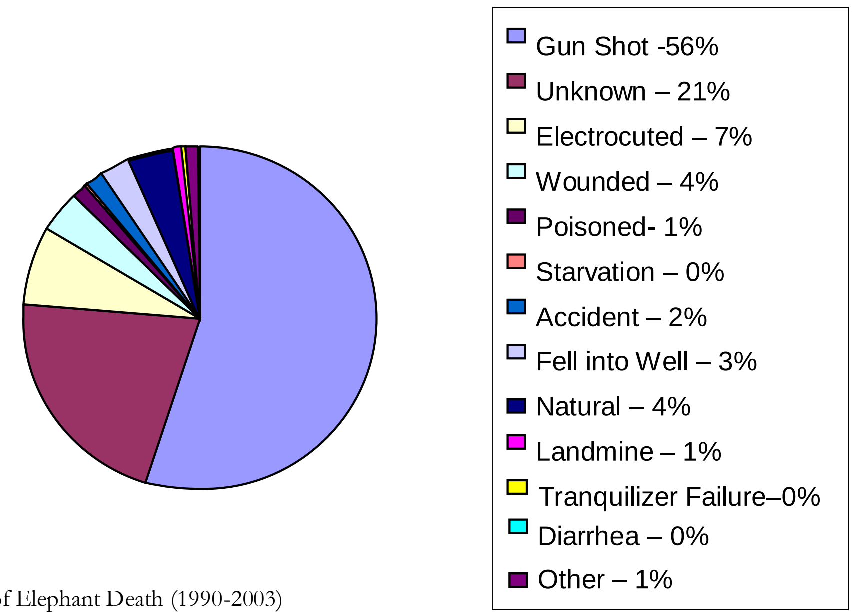


Figure 10: Causes of Elephant Death (1990-2003)

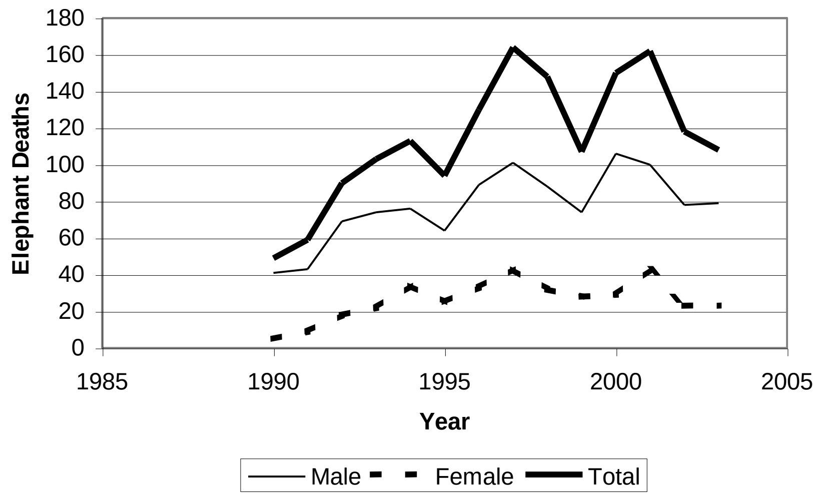


Figure 11: Inter-Annual Variation in Elephant Deaths. Variation by gender is shown.

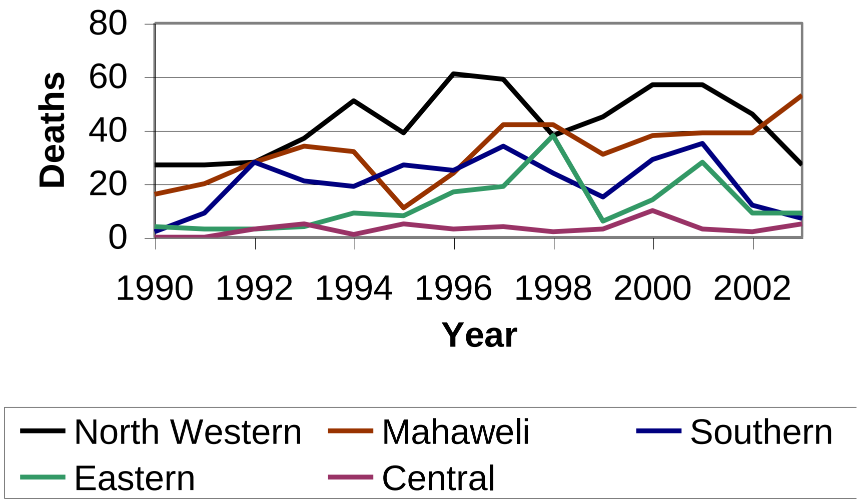


Figure 12: Inter-Annual Variation in Elephant Deaths. Variation by Regions is shown.

Male elephants are being killed at a ratio of 3:1 with respect to females (figure 11). Elephant populations are known to sustain an uneven gender ratio. However an even greater disparity is likely to be dangerous. There has been a gradual increase in elephant deaths from 1990 to 1997. According to the figure 12 there is an increasing trend of slightly more than one additional elephant is being killed each month every year. However, the period from January 1998 to December 2001 shows an extraordinary rise in elephant deaths; the number of elephant deaths has doubled during this period when compared with the previous 8 years or the subsequent two years.

6.3.2 Climate Influences on Elephant Deaths

Decadal Trends

Causes for the decadal scale trends in elephant deaths may be due to factors such as land settlements, civil war, variations in the quality of wildlife management, law enforcement or due to climatic factors. There were no large land settlement programs that took place during the period of peak elephant deaths. There is evidence that guns and ammunition that were liberally issued to "home guards" may have led to an increase in deaths of elephants. The civil war stopped in 2000 and that coincides with the peak in elephant deaths. Here we investigate the possible influences of climate by considering the long-term trends in rainfall and in elephant deaths.

We have computed the 60 month running average for both rainfall and deaths time series (Figure 13) to bring out the climate influences. In this instance, rainfall data for the Plains and Eastern Region was used. Figure 14 shows that long-term trend of the rainfall has a strong negative correlation with the long-term trend of the deaths for the Eastern Region (r = -0.87) and a more modest correlation with the Plains region (r=-0.53). This disparity is due to differences in the period from 1990-1996. Both of these correlations show statistical significance at the 95% level, which suggests that long-term climate trends relate to long-term trends in deaths. In particular, there is a deficit in rainfall coinciding with the periods with higher deaths. Further investigations of regional rainfall relationships with elephant death data are warranted.

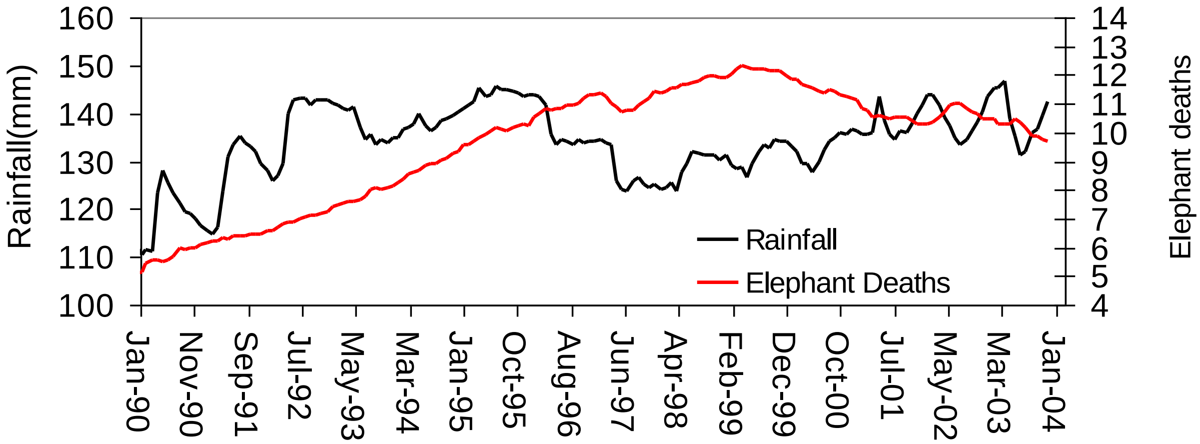


Figure 13: The long-term trends in elephant deaths and rainfall for the Eastern region estimated by computing running means of 60 months windows centered in the year in question.

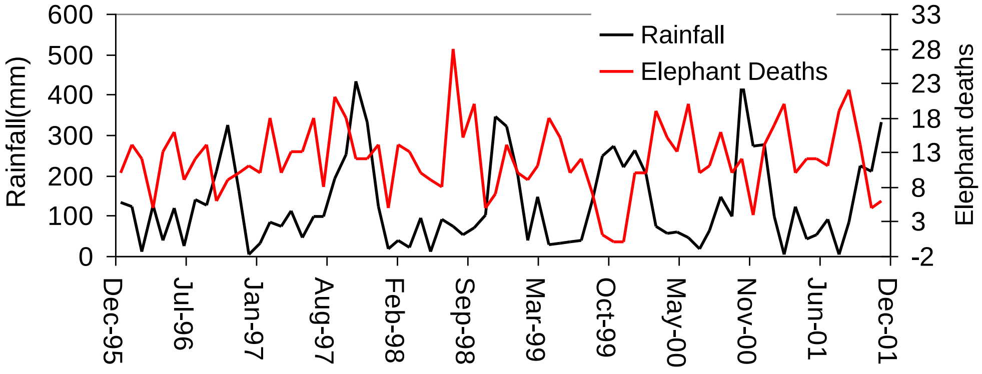


Figure14: Elephant deaths and rainfall for the Eastern Region from 1990-2003 after the long term trends were removed.

Seasonality

To assess the seasonal variations, the climatology of rainfall and elephant deaths were computed after the 60-month long-term trend was removed (figure 15). The elephant deaths show a monthly average that drops in November and December. It has a modest peak in March and September-October.

The Maha cultivation season lasts from October to March with some regional variation and the Yala cultivation season lasts from April to August with regional and also inter-annual variation. These crops are harvested around March and August. Thus the observed peaks may be related to the harvests of crops. However, the peaks are not that pronounced.

An alternative explanation related to climate is possible. The periods from January to March and July to August are periods of rainfall deficits in the regions of the island inhabited by elephants. Thereafter there is a subsidiary rainfall peak in May-June which in several years is insufficient to stave off the drought extending to August. This suggests that the peak droughts that coincide with the harvest seasons could also be leading to elephant deaths.

Both of these factors, the agricultural cycle and the drought have an influence given that availability of forage and water shall be affected by drought. The strong relationship between the long-term variability of rainfall and deaths indicates that drought plays a key role. Further analysis of drought episodes compared with episodes of abundant water shall provide further clarification of the relative role of the two.

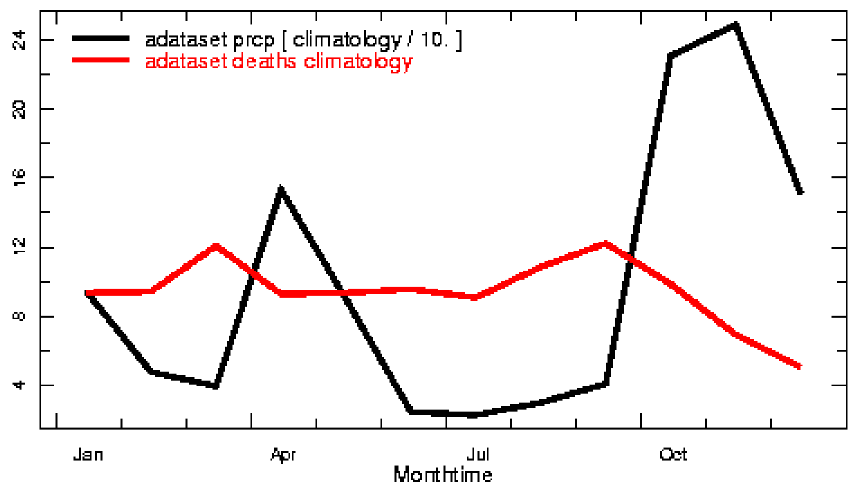


Figure 15: Monthly average elephant deaths and rainfall computed after the long-term trends identified in the previous figure 14were removed.

Inter-Annual Variability

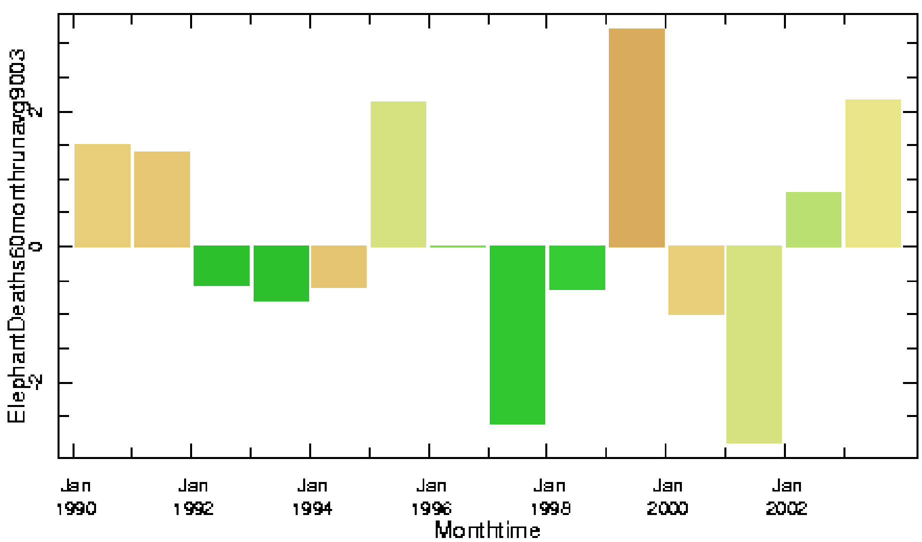


Figure16: The year-to-year departures of elephant deaths from the long-term trend are shown as a bar chart. Each bar is colored by the January to July rainfall

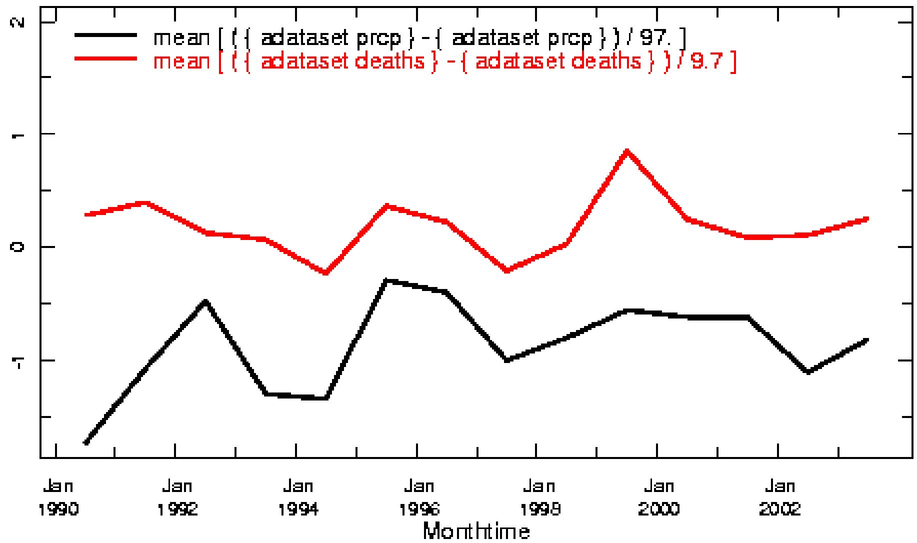


Figure17: Time series of the elephant deaths and the rainfall from October to December is shown

We have investigated the significant relationships between the rainfall during different seasons and elephant deaths. The analysis was undertaken between de-trended elephant deaths and rainfall. A table of relationships by quarter is provided in figure 16 and 17. We find that there is a weak relationship between January-March rainfall and the simultaneous elephant deaths (figure 17). Further investigations, shows that the rainfall from January to April or that from January to July has statistically significant relationships at 95% level with the annual elephant deaths (figure 18 and 19). The elephant deaths from July to December have a statistically significant inverse relationship with the January to June rainfall. During the period from October to December, there is no such relationship (figure 17). There is evidence to suggest that the rainfall during this period actually has a direct relationship with elephant deaths (i.e. flood-like condition during this period increases elephant deaths). However, this relationship is yet to be confirmed.

Overall, this analysis shows that the
a) Rainfall from January to April and January to June is inversely related to the elephant deaths during this period and can explain 25% of the variation in elephant deaths
b) Drought during January to July is related to elephant deaths in the subsequent 6 months.
c) The data suggests that floods lead to enhanced elephant deaths during October to December period. However these need to be confirmed.

This analysis needs further improvement based on the following:
a) find/create longer data sets
b) use regional data sets and regional analysis to assess the above findings.

6.4 Discussion

Overall, this preliminary analysis leads to the following conclusions. While other factors such as land use, the issues of guns and the management of human-elephant conflict are probably significant determinants of human-elephant-conflict, our analysis brings out a clear and robust role of climate even with the short data sets. The climate influence on the elephant deaths is evident in the analysis of the data with a 5 year running average and in the seasonal variations of elephant deaths that coincide with drought peaks in March or follow the months of peak drought in March and August. In addition, inter-annual analysis of the de-trended rainfall and elephant deaths shows that there are statistically significant relationships between drought in the first 7 months of the year and elephant deaths during the simultaneous period and the subsequent period.

6.5 References

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7. Outcomes, and Dissemination

7.1 Follow-Up Grants

This project's ground work provided us with the information necessary to carry out FECT future researches. High-resolution hazard analysis and a case-study of Disaster Risk for the Earth Institute's Disaster Hotspots are the future studies which will be carried out based on this study. The grant proposal for "Climate and Malaria" to the NOAA/NSF consortium depended substantially on the work carried out under this seed grant; the proposal was awarded to the IRI and research work will conduct by FECT.

7.2 Presentation of Findings

- Findings were presented at the IRI and Earth Institute Open House.
- These findings were presented to the Sri Lanka Department of Wildlife Conservation and the Mahaweli Authority's Environment Division in Sri Lanka in November 2004. These are two agencies primarily concerned with the management of elephants.
- A project website was developed to provide information at IRI.
- Six posters that document various aspects of the project were produced. Some of these were displayed at the Lamont Doherty Earth Institutes Open House in October 2004.

7.3 Presentations

June 2004: Prithiviraj Fernando, Center for Environmental Conservation and Research, "Elephant Management in Sri Lanka : A New Science Based Strategy", IRI, Palisades.

October 2004: Lareef Zubair, Climate and Endangered: Humans and Elephants in Sri Lanka, Open House, Lamont Doherty Earth Observatory, Palisades.

November 2004: Lareef Zubair and Zeenas Yahiya, Personal presentation to Director (P. Kariyawasam) and Sociologist (Hendahewa), Sri Lanka Department of Wildlife Conservation, Colombo 7.

December 2004: Lareef Zubair, Presentation to the Environment and Forest Conservation Division of the Sri Lanka Mahaweli Authority (in Sinhala).

7.4 Conference Proceedings

December 2004: Lareef Zubair, Joshua Qian, Neil Ward, Ousmane Ndiaye, Janaki Chandimala, Ruvini Perera, Vidhura Ralapanawe and Benno Blumenthal, Complementary Dynamical and Statistical Downscaling from a GCM: Maha rainfall over Sri Lanka, AGU Fall Meeting, San Francisco.

November 2004: Lareef Zubair, Benno Blumenthal, Janaki Chandimala, Ousmane Ndiaye, Ruvini Perera, Vidhura Ralapanawe and Neil Ward, Downscaling of Sri Lanka's Maha Rainfall from a GCM, International Conference on Sustainable Water Resources Management in the Changing Environment of the Monsoon Region, United Nations University, Colombo, Sri Lanka.

June 2006: Chandimala J., Siriwardhana, M., and Zubair L., Topographically informed high resolution temperature estimates for Sri Lanka, Sri Lanka Association for Advancement of Science, 62nd annual sessions, 2006

December 2007: Chandimala J., Hirsh S., Ralapanawa V., Zubair L., Vegetation Mapping and its Application in Drought Disaster Identification. International Conference on Humid Tropical Ecosystems: Changes, Challenges, Opportunities, UNESCO and Sri Lanka National Science Foundation. Kandy, 4th-9th December, Kandy, Sri Lanka.

December 2007: Zeenas Yahiya and L. Zubair, Human Elephant Conflict in Sri Lanka: Climate Impacts on Water and Fodder. International Conference on Humid Tropical Ecosystems: Changes, Challenges, Opportunities, UNESCO and Sri Lanka National Science Foundation. Kandy, 4th-9th December, Kandy, Sri Lanka

7.5 Posters

Introductory Material
Executive Summary
Sri Lanka at a Glance
Elephants in Sri Lanka

Climate
IRI Seasonal Climate Forecasts for Sri Lanka
High Resolution Climate Prediction for Sri Lanka
Climate Calendar of Sri Lanka

Human Elephant Conflict and Coexistence
Human Elephant Conflict
Wildlife Management Options

Foundation for Environment, Climate and Technology,
C/o Maintenance Office, Mahaweli Authority of Sri Lanka,
Digana Village, Rajawella, Sri Lanka
Tel: +94-81-2376746