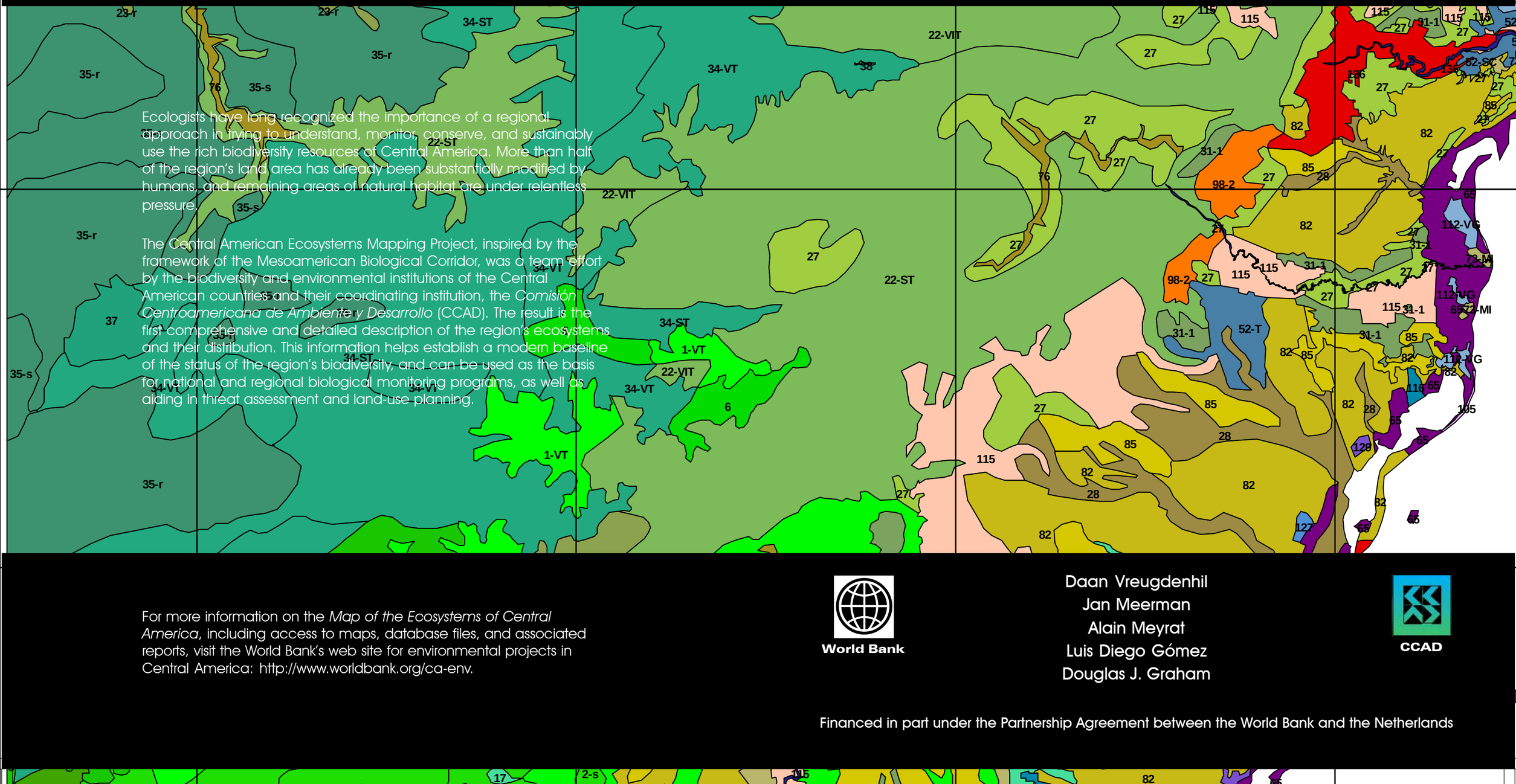
Map of the Ecosystems of Central America

Final Report



Ecologists have long recognized the importance of a regional approach in trying to understand, monitor, conserve, and sustainably use the rich biodiversity resources of Central America. More than half of the region's land area has already been substantially modified by humans, and remaining areas of natural habitat are under relentless pressure.

The Central American Ecosystems Mapping Project, inspired by the framework of the Mesoamerican Biological Corridor, was a team effort by the biodiversity and environmental institutions of the Central American countries and their coordinating institution, the *Comisión Centroamericana de Ambiente y Desarrollo* (CCAD). The result is the first comprehensive and detailed description of the region's ecosystems and their distribution. This information helps establish a modern baseline of the status of the region's biodiversity, and can be used as the basis for national and regional biological monitoring programs, as well as aiding in threat assessment and land-use planning.

For more information on the *Map of the Ecosystems of Central America*, including access to maps, database files, and associated reports, visit the World Bank's web site for environmental projects in Central America: http://www.worldbank.org/ca-env.

World Bank

Daan Vreugdenhil
Jan Meerman
Alain Meyrat
Luis Diego Gómez
Douglas J. Graham

CCAD

Financed in part under the Partnership Agreement between the World Bank and the Netherlands

MAP OF THE ECOSYSTEMS OF CENTRAL AMERICA

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Daan Vreugdenhil
Jan Meerman
Alain Meyrat
Luis Diego Gómez
Douglas J. Graham

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This report may be cited as:

Vreugdenhil, Daan, Jan Meerman, Alain Meyrat, Luis Diego Gómez, and Douglas J. Graham. 2002. *Map of the Ecosystems of Central America: Final Report.* World Bank, Washington, D.C.

The regional map may be cited as:

World Bank and CCAD. 2001. "Ecosystems of Central America (ArcView regional map files at 1:250,000)." World Bank, Comisión Centroamericana de Ambiente y Desarrollo (CCAD), World Institute for Conservation and Environment (WICE), and the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Washington, D.C. (http://www.worldbank.org/ca-env).

The findings, interpretations, and conclusions expressed in this study are those of the authors and should not be attributed in any manner to the World Bank, its affiliated organizations, members of its Board of Executive Directors or the countries they represent. The boundaries, colors, denominations, and other information shown on any maps do not imply any judgement on the legal status of any territory or the endorsement or acceptance of such boundaries.

To download additional copies of the report or access the ecosystem maps, database files, and other materials associated with the mapping project, visit the World Bank's web site for environment projects in Central America: http://www.worldbank.org/ca-env.

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Scientific Team

Lead Scientists—International Team

Ir. Daan Vreugdenhil, Ecologist, World Institute for Conservation and Environment (WICE) (Technical Coordinator)
Douglas J. Graham, M.Sc., Biodiversity Specialist, World Bank (Task Manager)
Dr. Susan Felicity Iremonger, Vegetation Scientist, World Conservation Monitoring Center (WCMC)
Dr. Douglas Muchoney, GIS Scientist, Conservation International (formerly with Boston University)
Dr. Luis Diego Gómez, Vegetation Scientist, Organization for Tropical Studies (OTS)
Alain Meyrat, M.Sc., Ecologist, WICE
Ir. Jan Meerman, Ecologist, WICE
Dr. Jeffrey Jones, Centro Agronómico Tropical de Investigación y Enseñanza (CATIE)

Lead Scientists—National Teams

Belize
Ir. Jan Meerman, Ecologist, WICE
Wilber Sabido, GIS Specialist, Programme for Belize
Dr. Susan Felicity Iremonger, Vegetation Scientist, WCMC

Costa Rica
Luis Diego Gómez, Ph.D., Vegetation Scientist, OTS
Wilberth Herrera, M.Sc., Geographer–Climatologist

El Salvador
Dr. Nohemy Ventura, Botanist, Universidad de El Salvador
Ing. Raul F. Villacorta, Botanist
Ir. Peter Sloot, GIS Scientist/Soil Scientist, DLV Agriconsult, Netherlands

Guatemala
Prof. Dr. Cesar Castañeda, Botanist
Prof. Dr. Juan José Castillo Montt, Botanist, Universidad de San Carlos
Maurice Carignan, M.Sc., GIS/Remote Sensing Vegetation Specialist, Tecsult (Canada)

Honduras
Dr. Thelma M. Mejía, Botanist, Universidad Autónoma de Honduras (UNAH)
Ing. Cristobal Vasquez, Forester, GIS Specialist, Administración Forestal del Estado/Corporación Hondureña de Desarrollo Forestal (AFE-COHDEFOR)
Dr. Susan Felicity Iremonger, Vegetation Scientist, WCMC
Dr. Paul House, Vegetation Specialist, UNAH
Carlos Cerrato, M.Sc., Aquatic Ecologist, UNAH

Nicaragua
Alain Meyrat, M.Sc., Ecologist, MARENA/ABC
Dr. Alfredo Grijalva, Botanist
Ir. Rob Beck, GIS Scientist/Vegetation Scientist, NEO (Netherlands)
Ir. Daan Vreugdenhil, Ecologist, WICE
Victor Cedeño, Ecologist, MARENA/ABC

Panama
Dr. Mireya D. Correa, Botanist, STRI
Dr. Luis Carrasquillo, Botanist, Universidad de Panamá
Martín Mitre, Botanist
María Stapf, Botanist, STRI
Valerie Kapos, Ph.D., Botanist, WCMC
Dr. Abdiel J. Adames, Project Director, Louis Berger (Panama)

Acknowledgements

Production of the Central American Ecosystems Map was a team effort by the biodiversity and environmental conservation institutions of the Central American countries and their coordinating institution, the *Comisión Centroamericana de Ambiente y Desarrollo* (CCAD). However, it also is fair to say that the map is the culmination of decades of research by ecologists from across the region, many of whom have been associated with national universities.

The project team—under the overall coordination of Daan Vreugdenhil of the World Institute for Conservation and Environment (WICE) and Douglas J. Graham of the World Bank—is grateful for the vision and support of Mauricio Castro, Executive Director of CCAD, and Lorenzo Cardenal, Director of CCAD's Mesoamerican Biological Corridor (MBC) project. The *Centro Agronómico Tropical de Investigación y Enseñaza* (CATIE) in Costa Rica was contracted to prepare a final ArcView file of the regional map based on the national map files. Table 1 in the main report provides a complete list of collaborating institutions and key officials. The main participating scientists are listed on the previous page.

This effort was made possible by financing from a variety of sources: the Directorate-General for International Cooperation (DGIS) of the Netherlands; the Global Environment Facility (through national MBC projects implemented by the World Bank and a regional MBC project implemented through the UNDP); the participating countries; and the World Bank. The initiative cost roughly $2 million and was carried out between early 1999 and mid-2001.

We particularly would like to recognize the encouragement of Mark E. Cackler, John Redwood, Teresa Serra, and Arsenio Rodríguez of the World Bank, Ton van der Zon of the Directorate-General for International Cooperation of the Netherlands, and Sjef IJzermans of the Netherlands Embassy in Washington.

Words of appreciation also go to supporting staff of the World Bank: Marie-Claude Haxaire, Diana Montas, Lia van Broekhoven, and in particular to Peter Brandriss for his editorial assistance.

Abbreviations and Acronyms

ABC	Atlantic Biological Corridor (Nicaragua)
AFE/ COHDEFOR	Administración Forestal del Estado/ Corporación Hondureña de Desarrollo Forestal
ANAM	Autoridad Nacional del Ambiente (Panama)
AVHRR	Advanced Very High Resolution Radiometer
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza
CBMAP	Corredor Biológico Mesoamericano del Atlántico Panameño (Panama)
CCAD	Comisión Centroamericana de Ambiente y Desarrollo
DGIS	Directoraat-Generaal Internationale Samenwerking (Directorate-General for International Cooperation) (Netherlands)
EROS	Earth Resources Observation Systems Data Center (USGS)
FAO	Food and Agricultural Organization (United Nations)
GEF	Global Environmental Facility
GIS	Geographic Information System
GPS	Global Positioning System
IDB	Inter-American Development Bank
ILWIS	Integrated Land and Water Information System (GIS program)
INAB	Instituto Nacional de Bosques (Guatemala)
INBio	Instituto Nacional de Biodiversidad (Costa Rica)
INETER	Instituto Nicaragüense de Estudios Territoriales
IPGH	Instituto Panamericano de Geografía e Historia
ITC	International Training Centre (Netherlands)
IUCN	World Conservation Union
MARENA	Ministerio del Ambiente y los Recursos Naturales (Nicaragua)
MARN	Ministerio de Medio Ambiente y Recursos Naturales (El Salvador)
MBC	Mesoamerican Biological Corridor
MINAE	Ministerio del Ambiente y Energía (Costa Rica)
MODIS	Moderate Resolution Imaging Spectroradiometer
MSS	Multispectral Scanner
NASA	National Aeronautics and Space Administration (United States)
NGO	Nongovernmental Organization
ODA	Overseas Development Agency (Great Britain)
OTS	Organization for Tropical Studies (Costa Rica)
PAAR	Proyecto de Administración de Áreas Rurales (Honduras/World Bank)
PROARCA	Programa Ambiental Regional para Centroamérica (USAID)
PROBAP	Proyecto de Biodiversidad en Áreas Prioritarias (Honduras/World Bank)
SICA	Sistema de Integración Centroamericana
SINAC	Sistema Nacional de Áreas de Conservación (Costa Rica)
SPOT	Satellite pour l'Observation de la Terre
STEP	System for Terrestrial Ecosystem Parameterization
STRI	Smithsonian Tropical Research Institute (Panama)
TM	Thematic Mapper
TNC	The Nature Conservancy
UNAH	Universidad Autónoma de Honduras
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific, and Cultural Organization
USAID	United States Agency for International Development
USGS	United States Geological Survey
USNCS	United States National Classification System
UTM	Universal Transverse Mercator
WCMC	World Conservation Monitoring Center
WICE	World Institute for Conservation and Environment
WWF	World Wide Fund For Nature

Foreword

Biodiversity knows no borders. This is particularly true for the small and highly interconnected countries of the Mesoamerican land bridge between North and South America that stretches from Guatemala and Belize in the north, through El Salvador, Honduras, Nicaragua, Costa Rica, and finally to Panama in the south.

Ecologists have long recognized that to understand, monitor, conserve, and sustainably use the biodiversity resources of Central America, these resources must be approached and studied from a regional perspective. This has become even more pressing in the context of the shared vision of conservation and rural development represented by the Mesoamerican Biological Corridor (MBC), and in implementing regional approaches to environment issues under the guidance of the *Comisión Centroamericana de Ambiente y Desarrollo* (CCAD), which represents all the environmental ministries of the region.

Until now, no detailed portrait has been available of the status and distribution of the ecosystems of Central America. Rough overall deforestation figures have been calculated, but we did not know of the full complexity of ecosystems and their distribution, where the major threats were, and how well represented different ecosystems were in Central America's protected areas.

From 1999 to early 2001, under the auspices and general coordination of CCAD and the World Bank, collaborating governmental and nongovernmental environmental institutions of the CCAD member countries completed a new ecosystems map to meet these challenges. In each country a national team of biologists and supporting specialists worked over a two-year period to map their ecosystems. The lead biologists of the national teams participated in a process of synchronized production and harmonization of production methodologies under the overall direction of the World Bank. The national biologists were complemented by a team of international specialists.

The primary objective of the mapping project was to map and describe the present distribution of ecosystems in Central America. This information is critical to establishing a modern baseline of the status and location of the region's biodiversity, and will be the basis for national and regional biological monitoring programs. This information will also allow the region to move toward the geographical definition of the MBC and will assist the countries in planning long-term land use.

The maps and data collected by the Central American experts will need to be studied in detail and corrected and improved as necessary, and regional collaboration will be essential for mounting a coherent monitoring strategy and maintaining the regional integrity of the map. However a glance at the map reveals two obvious conclusions:

a) The Mesoamerican Biological Corridor is more than a concept: from the viewpoint of a discerning observer high above the earth, real corridors of natural habitat still stretch from southern Mexico to Colombia, even though they are precarious and fragmented in many areas. This reaffirms the importance of Mesoamerica as one of the world's most important biological hotspots and as a biological highway between North and South America.

b) The threat to the MBC is serious and its future is precarious. The pace at which natural habitats have been converted in the past few decades is astonishing. The map shows that at least half of the Central American Isthmus has already been substantially modified by humans. These "gray areas" contain, at best, only tiny and unconnected patches of natural habitats. The region is still beset by serious poverty and underdevelopment and the population is expected to double in the next 20 to 30 years. Central Americans will face an enormous challenge conserving healthy and viable areas that are representative of their biological and natural resources heritage. The concept of the MBC itself, combining the needs of both development and conservation, is a highly promising response to this challenge.

John Redwood, Director
Environmentally and Socially Sustainable Development
Latin America and the Caribbean Regional Office
The World Bank

1. Introduction and Objectives

Although now interrupted in places and under relentless pressure from the agricultural frontier, essentially intact strips of natural habitat still remain linking Mexico to Colombia. These strips of natural habitat, considered within the framework of a collective determination to ensure their conservation and sustainable use as part of an overall strategy of rural development, are referred to as the Mesoamerican Biological Corridor (MBC).[1]

Conserving the biological and sociocultural riches of these areas while promoting sustainable use and development has become a priority for all the Central American countries as well as the global community. The concept of the MBC has been embraced by the heads of state of the Central American countries, endorsed by various intergovernmental treaties and organizations, and has become a central orientation of environmental and development policies of each of the countries involved.

Originally the MBC was a cooperative effort of the seven countries from Belize to Panama, but now it is generally recognized as also embracing five of Mexico's southern states and the department of Chocó in Colombia.

The *Comisión Centroamericana de Ambiente y Desarrollo* (CCAD—the Central American Commission on Environment and Development), which represents the environment ministries of all the countries of Central America, plays a critical role in developing, coordinating, and promoting the MBC. In addition, innumerable other bilateral and multilateral organizations, donors, the Global Environment Facility (GEF), nongovernmental organizations (NGOs), community-based organizations, governmental organizations, and other stakeholders all contribute in important ways to the consolidation of the MBC.

To achieve the goal of consolidating the MBC, a better understanding was needed of the nature and current extent of the region's great wealth of biological diversity. Thus originated the determination to produce the region's first detailed assessment of its ecosystems.

1.1 Objectives of the Mapping Project

Inspired by the framework of the MBC, the primary objective of the mapping project was to map and describe the ecosystems of Mesoamerica (Belize, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, and Panama) using a comprehensive, regionally endorsed, classification system.[2] The map and associated data represent a 1997–99 baseline for the region and form the foundation for a regional monitoring program of changes in natural habitat.

Some of the key benefits expected are:

- Input to the geographical delineation of the MBC;
- Inputs for national conservation and rural development strategies;
- Prioritization of protected areas (through gap analyses) given that our ecosystems are a proxy for unique sets of animal and plant communities and ecological processes;
- Assessment of the conservation value of protected areas;
- Creation of a baseline for further ecological studies and biodiversity monitoring, particularly in the context of global warming;
- Better information for environmental impact assessments; and
- Enhanced understanding of the region's ecology on the part of national and international scientists.

1.2 Availability of Our Data

All data and information produced in the context of this project have been made publicly available. The following digital information can be accessed from the World Bank web site for environmental projects in Central America (http://www.worldbank.org/ca-env):[3]

- ArcView shapefiles by country and an integrated file for the region. The files and metadata are graciously hosted by Earth Resources Observation Systems (EROS) Data Center of the USGS;
- Database files by country and an integrated regional database;
- Adobe Acrobat PDF files of this final report and its annexes;
- Additional associated reports;
- Printable files of the national maps (at a scale of 1:250,000);

1. For more information on the MBC refer to the web site of the GEF/CCAD Regional MBC Project (http://www.biomeso.net/).

2. Islands more than 100 kilometers from the mainland are not included on the map.

3. See also the WICE web site for additional related files at http://birdlist.org/cam/central_america.htm.

- Reduced resolution printable PowerPoint files of the individual sheets of the integrated regional map;
- Processed files of remote satellite imagery (through the EROS site) available at cost; and
- Many additional methodological documents.

The original geographic information system (GIS) files for each country belong to and are maintained by each country. These are available in most countries on CDs distributed by the participating institutions. Efforts are underway to agree on a common regional data repository for the maps and databases as they are corrected and refined.

2. Methodology

Figure 1 presents a schematic overview of the methodology of the Ecosystem Mapping Project. Four principal thematic areas are outlined: (a) team development and coordination, (b) development of the methodology, (c) data collection, and (d) data processing. The following sections describe the approach adopted in each of these areas.

2.1 Team Development and Coordination

Selection of International and National Specialists

The mapping project was executed by national teams in each of the participating countries, with coordination and assistance from an international team. At an early stage a Technical Coordinator (Vreugdenhil) was selected, as well as a team of international scientists with extensive experience in vegetation mapping and use of geographic information system (GIS) applications and remote sensing. They are listed at the front of this report.

In each country, authorities for biodiversity conservation and/or mapping were contacted and they provided important support to the project throughout its duration. Many of these authorities are listed in Table 1.

Production options were discussed with the national authorities, and in each country collaborating scientists from national universities or other institutions were contacted. International bidding/contracting for a lead firm was carried out in Guatemala and Panama, strengthened with national lead botanists and the international support team. In all other countries, national teams were established, each consisting of national scientists supported by a small team of international scientists. The lead scientists of the national teams are listed on page iv of this report.

Training and Coordination Events

A number of exchanges were needed between all participants to decide on the methodology and to exchange experiences during the course of the work. In addition, once a method and approach had been decided, all the participating scientists needed to be trained in the methodology, interpretation, and handling of remotely sensed images, use of GIS applications, etc. In total, about 20 national scientists and government officials participated in intensive training sessions and many more in the various meetings and workshops that were organized.

The Ecosystem Mapping Project involved five principal workshops/training sessions during the course of the mapping process. The dates and topics of those session are listed in Table 2.

Regional harmonization and compatibility between the different national efforts has been attained through a variety of mechanisms:

- Joint training;
- Coordination through frequent visits by the Technical Coordinator (Vreugdenhil) to each of the participating countries;
- Promotion by the World Bank and CCAD of intercountry coordination at various political, technical, and institutional levels;

Table 1. Collaborating Authorities from Government and Other Institutions

Country	*Officer*	*Collaborating institutions*
Belize	Noreen Fairweather	Land Information Center
	Joy Grant	Programme for Belize
Guatemala	Francisco López	Instituto Nacional de Bosques (INAB) / Comisión Nacional de Biodiversidad
El Salvador	Francisco Delgado	Ministerio de Ambiente y Recursos Naturales (MARN)
Honduras	VictorArchaga	AFE/COHDEFOR
	Ricardo Arias	Proyecto de Administración de Áreas Rurales (PAAR) (World Bank project)
	Eduardo Canales	PROBAP (World Bank GEF project)
	Sergio Midence	Proyecto de Administración de Áreas Rurales (PAAR)
Nicaragua	Leonardo Chávez García Cantarero	Ministerio del Ambiente y los Recursos Naturales (MARENA) Atlantic Biological Corridor (ABC) (World Bank GEF project)
	Victor Cedeño	ABC
Costa Rica	Damaris Garita	Ministerio del Ambiente y Energía (MINAE)
	Luis Diego Gómez	Organization of Tropical Studies (OTS)
Panama	Iván Valdespino	CBMAP/ANAM (World Bank GEF project)
	Gina Castro	CBMAP/ANAM

Figure 1. Central America Ecosystems Mapping Project

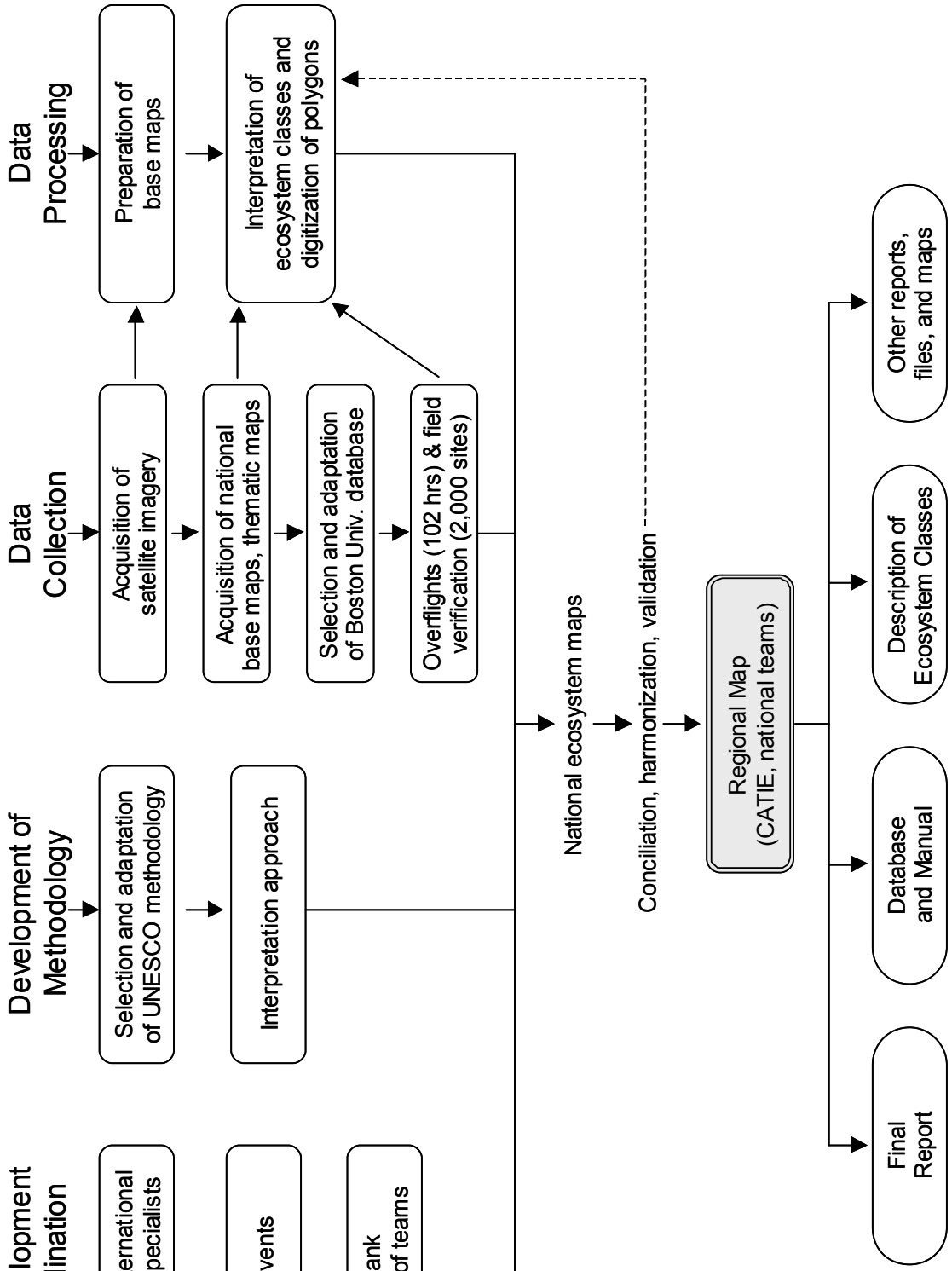


Table 2. Preparatory and Harmonization Workshops

Dates	*Site*	*Topics*	*Results*
March 15-18, 1999	Shepherdstown, West Virginia, United States	Preparatory retreat for revision of methodological options and project execution	Workplan; methodological proposal for April 1999 workshop
Apr. 26-28, 1999	Organization for Tropical Studies (OTS), La Selva, Costa Rica	Selection of methodology with the lead members of the country teams and the representatives of governmental institutions for biodiversity	Agreement on application of the UNESCO classification method
May 25-June 2, 1999	OTS, Las Cruces, Costa Rica	Training course for lead specialists of country teams	Training on classification methodology, image interpretation, use of database
Sep. 28, 1999	Guatemala City, Guatemala	SICA-CCAD/World Bank "International Workshop on the Central America Ecosystems Map"	Endorsement of methodology by sponsoring institutions and SICA-CCAD
Nov. 19-25, 2000	CATIE, Turrialba, Costa Rica	Pre-preparation of transborder integration with one scientist per country	Draft final integrated map
Nov. 29-Dec 1, 2000	Managua, Nicaragua	Final revision of integrated map	Approval of final nomenclature, resolution of transborder issues, formation of vegetation working group

- Creation of a cross-country classification integration table;
- Organization of a final integration workshop; and
- Preparation of ecosystem descriptions.

2.2 Development of Ecosystem Classification Methodology

Overview of Classification Systems

Various classification schemes have been used to describe natural habitat units:

a) Ecoregions
b) Life zones system of Holdridge
c) Floristic classification systems
d) Physiognomic and physiognomic/floristic classification systems
e) Combined physiognomic/ecological classification systems (such as the UNESCO system).

In the Central America mapping project, a modified version of the UNESCO system was used. Before explaining it more in detail, we look at some of the advantages and disadvantages of other approaches and their use in Central America.

Ecoregions

Ecoregions represent a typology of natural habitat units most appropriate for continental scales of about 1:5,000,000 or greater. A joint WWF/World Bank study (Dinerstein et al. 1995) on conservation priorities in Latin America and the Caribbean defined an ecoregion as:

> A geographically distinct assemblage of natural communities that share a large majority of their species, ecological dynamics, and similar environmental conditions and whose ecological interactions are critical for their long-term persistence.

In the 1995 study, 21 ecoregions were defined for Central America. This map has subsequently been revised somewhat and a book with a new map and descriptions of each of the ecoregions is forthcoming from WWF.

This definition of an *ecoregion* closely resembles our working definition of an *ecosystem* but differs dramatically in the scale at which is it defined. The ecoregions of Latin American and the Caribbean were mapped at a scale of about 1:10,000,000, which is helpful for conservation planning at continental scales, but is not a sufficient level of detail for conservation and planning purposes at the national or local scale. By contrast, the Central American Ecosystem Map is at a scale of 1:250,000.

The life zones classification system of Holdridge

In Latin America, the description of terrestrial ecological formations has been overwhelmingly based on the life zones classification system of Holdridge et al. (1971) and Holdridge (1978). Its use has traditionally been, and continues to be, so important in Central America that we describe it in some detail here.

This method assumes that vegetation classes vary as a function of certain climatic and altitudinal gradients. It is critical therefore to note that the Holdridge system is *predictive* rather than *descriptive*, unlike all other classification systems described here.

Holdridge affirms that a global system of life zones can be established on the basis of precipitation and temperature. He works with the concept of "biotemperature," which takes into account the optimal temperature range for plants. Another temperature factor he takes into consideration is the decrease in temperature with the increase of elevation, which is about 6° C for every 1,000 meters. A third factor he takes into consideration is evapotranspiration, for which he developed his own formula. Holdridge then associated a typical vegetation type with the different life zones he determined from precipitation, biotemperature, altitude, and evapotranspiration.

When it was developed, the Holdridge life zones method offered an interesting solution for habitat differentiation at a time when aerial photographs (very expensive, often almost impossible to obtain, or militarily classified) were scarce and satellite imagery was very coarse or not yet available to the public. His system also offered the advantage of allowing life zones to be determined using data widely and cheaply available from simple weather stations (but at the same time this was a disadvantage for those areas without such stations).

However, the Holdridge life zone maps are predictive for natural communities; they don't inform the user about the presence or absence of a natural community type, its actual appearance (physiognomy) as observed in the field, or its replacement by an anthropic system. It does not take into consideration major dynamic change factors such as fire or drainage.

In the 1970s, life zone maps were made for most of the countries of Central America, with between 8 and 19 classes per country. The delineation of those classes was coarse given the limited quantity and poor quality of the underlying data. Subsequent attempts by vegetation ecologists in Central America to generate more detailed maps using the Holdridge system have generally failed (Paul House, pers. comm., 2001).

Floristic classification systems

Floristic classification systems rely on species composition or species groups, rather than physiognomic patterns of the dominant species. Patterns of succession, disturbance, history (including paleoecology), and natural communities are better assessed through floristic composition than physiognomy (Glenn-Lewin and van der Maarel 1992). The most systematic vegetation classifications that have been developed are that of the Zürich-Montpellier or Braun-Blanquet system and the association/habitat type system of Daubenmire. Each of these systems uses a basic floristic unit called the association, defined as "a plant community type of definite floristic composition, uniform habitat conditions and uniform physiognomy." Braun-Blanquet (1928, cited in Moravec 1993) defined the association as "a plant community characterized by definite floristic and sociological (organizational) features which shows, by the presence of character-species (exclusive, selective, and preferential), a certain independence." Plant associations that share diagnostic species are grouped into higher floristic units called alliances, orders, and classes (see Pignatti et al. 1995). "Character species" are based on the concept of fidelity: the degree to which a species is limited to a definite association (or to other floristic types higher or lower in the hierarchical taxonomy). Character species and others of high constancy (that is, those present in at least 60 percent of the stands), along with ecological and geographical considerations, help to define an association.

Floristic methods can reveal local and regional patterns of vegetation. However, they rely on intensive field sampling and detailed knowledge of the flora, both of which are a problem in the poorly known but species-rich tropics. It also requires substantial quantitative analysis of stand data to determine the diagnostic species groups. The use of diagnostic species works well in temperate climates and nonforest habitats in the tropics (Cleef, pers comm., 2000), but in tropical forests, the system tends to be difficult to use.

Physiognomic and physiognomic/floristic systems

Ecosystems or natural habitat units can be defined solely on their physiognomy (their physical structure or appearance). The physiognomic approach assumes that each specific life form reflects a strategy that has been selected under ecological pressures, and that the composition of life forms in a vegetation type is governed by these strategies (Whittaker 1975; Dansereau et al. 1966). Since physiognomic attributes are highly influenced by dominant species, recognition of a physiognomic assemblage depends on the coexistence of species in a given area (Bourgeron and Engelking 1994). These coexisting species can be classified further by floristic methods. These have been little used in Central America and have the disadvantage of being unfamiliar to local ecologists. They also have the drawback of insufficiently capturing or estimating information on biological diversity and ecological processes.

Several attempts have been made to combine physiognomic and floristic systems. Several studies (Rübel 1930; Whittaker 1962; Westhoff 1967; Webb et al. 1970; Beard 1973; Werger and Sprangers 1982; Taylor 1959 in Nicaragua; Grossman et al. 1998) have found good correspondence between floristic and physiognomic classifications of the same vegetation. Läuer (in the 1950s) did a classification of vegetation forms in El Salvador

based on physiognomic and climatic criteria. In Central America, Wright et al. (1959) developed a physiognomic/floristic vegetation classification for Belize.

The United States National Classification System (USNCS) is noteworthy in that it combines a physiognomic approach with a floristic approach. A major drawback of the USNCS is that it has only been used at a fairly detailed scale in the United States (Grossman et al. 1998) although the PROARCA/TNC map of Central America, produced at a scale of 1:1,000,000, is officially based on the USNCS.

The UNESCO physiognomic/ecological classification system

In 1974 Mueller-Dombois and Ellenberg developed "A Tentative Physiognomic–Ecological Classification of Plant Formations of the Earth" on behalf of UNESCO. It is hereafter referred to as the "UNESCO system" (see the World Bank web site for a digital version of the original publication). It describes the aboveground or underwater vegetation structures and cover as observed in the field, described as "plant life form." This classification is fundamentally a species-independent, physiognomic, hierarchical vegetation classification system that also takes into account ecological factors such as climate, elevation, hydric regimes, human influences (such as grazing), and survival strategies (such as seasonality).

The different levels of the classification hierarchy are distinguished by different symbols:

I, II, etc.	=	Formation class
A, B, etc.	=	Formation subclass
1, 2, etc.	=	Formation group
a, b, etc.	=	Formation
(1), (2), etc.	=	Subformation
(a), (b), etc.	=	Further subdivisions

The formation classes in the UNESCO hierarchy are the following:

I. *Closed Forests*. Formed by trees at least 5 meters tall with their crowns interlocking, covering 65 percent of the sky or more.
II. *Woodlands.* Open stands of trees formed by trees at least 5 meters tall, with most of their crowns not touching each other, but covering at least 30 percent of the sky.
III. *Scrub*. Shrublands or thickets, mainly composed of woody phanerophytes (bushes or small trees) between 0.5 and 5 meters tall. Crowns may or may not touch, but cover at least 30 percent of the sky.
IV. *Dwarf-Scrub and Related Communities.* Rarely exceeding 50 centimeters in height (sometimes called heaths or heath-like formations.)
V. *Terrestrial Herbaceous Communities.* Grasses, graminoid and other herbaceous plants are predominant in the cover. Woody plants (trees or shrubs) may be present, but cover no more than 30 percent. (Within this category, savannas, steppes, or prairies are described. It is important to note that those classes do not refer to geomorphological conditions. Savannas or prairies may be on flat, hilly, or steep terrains.)
VI. *Deserts and Other Scarcely Vegetated Areas.* Bare mineral soil or rocks determine the aspect. Plants are scattered or may be absent (subdeserts are included in formation classes III to V);
VII. *Aquatic Plant Formations.* Nonmarine formations composed of rooted and/or floating plants that endure or need water covering the soil constantly or at most times of the year.

These seven formation classes cover all the ecosystems on Earth except open water and frozen ecosystems (the authors of the UNESCO system suggest using a geomorphological classification for deserts without vegetation but they do not elaborate such a system).

The subdivisions of the UNESCO system below the level of formation class vary considerably in how they are defined. Depending on the general habitat type, subdivisions may be based on purely physiognomic features, ecological processes such as flooding, or take into account altitudinal or climatic conditions. This flexibility of the UNESCO system allowed its original authors to design a system that reflected the varying relative importance of different factors in different types of ecosystems, recognizing that a taxonomy of ecosystems cannot rigidly consider one factor to be more important than another.

Over the past decades, The UNESCO classification has proved to be easily applied in the field and it has been used on all continents and for vegetation classes of all climates. The system is intuitive and can be readily learned even by relatively inexperienced biologists because no taxonomic knowledge is required. It is suitable for the interpretation of aerial photographs, and more recently it has turned out to be well adapted to working with remotely imaged satellite photos.

Puig et al. (1981) produced a bioclimatic vegetation map of South America combining the UNESCO classification with climatic data. The map, based on 600 images of Landsat 1 and 2, was probably the first major attempt in Latin America to use satellite imagery for vegetation mapping.

The UNESCO classification system is well known in Central America. The first national UNESCO-based physiognomic vegetation map in the region was made in 1986 for Costa Rica by Gómez (1986a).

Another major use of the UNESCO classification was the ecosystems map for Belize. It was produced with joint financing from IDB and USAID in cooperation with the Programme for Belize (Iremonger and Brokaw 1995). It was also the first map in the region that made an attempt to integrate aquatic ecosystems in a UNESCO-type classification. The Belize map was followed by the ecosystems map for Honduras (Iremonger 1997), financed through a World Bank credit.

It should be noted however, that Iremonger and Brokaw (1995) and Iremonger (1997) used a very liberal interpretation of the UNESCO system whose nomenclature was adapted for their needs.

Adaptation of the UNESCO Classification to Central America

Given the strengths and weaknesses of the different classification systems available, and particularly given the strong prior experience of the Central American experts with the UNESCO system, the latter was chosen for this mapping project. This decision was taken during the project's Guatemala workshop in September 1999 to finalize a methodological approach. It was unanimously endorsed by the representatives of all seven participating countries.

However, a number of modifications were made to the system and additional modifications and changes were made over the course of the next two years to adapt the system to Central America (hereafter described as the "Central American UNESCO Classification"). All changes and modifications were proposed and discussed in the workshops bringing together the international specialists and representatives from all countries.

Under the Central American UNESCO classification an ecosystem is defined as *a relatively homogenous unit (distinguishable at our working scale of 1:250,000) of interacting organisms, ecological processes, and geophysical elements such as soil, climate, and water regime. An ecosystem is principally defined by the physical appearance and structure (physiognomy) of its dominant plant species and also by its predominant ecological processes such as fire, flooding, or grazing.*

Thus defined, an ecosystem is believed to be a proxy for a relatively homogenous and unique community of species and allows the use of our data to approximate the information that one might obtain from comprehensive faunal and floristic inventories.

The following text and Annex 1 (the legend to the Central American Ecosystems Map) describe the major elements of our classification.

Although no such formal decision was ever made and transmitted to the country teams, formation class II (Woodlands) was not used by any of the country teams. Obviously there are areas of habitat that have a forest cover less than 65 percent (the cut-off for formation I, Closed Forests) and greater than 30 percent (cut-off for formation V, Savannas) but these were considered to exist only as narrow, poorly defined transtion zones not mappable in their own right, too small to be mapped, or were mapped as anthropically intervened closed forests. Further field work may identify naturally occuring, well-defined, formation II woodlands. We consider a likely candidate to be oak formations in rocky submontane areas.

Descriptions were made for each of the recognized ecosystem classes. These are presented in "Descripciones de los Ecosistemas de America Central," published seperately from this report and available only in Spanish. We consider these descriptions to be a work in progress and expect them to be refined and improved in the future. Subdivisions are mentioned within such classes. The descriptions combine information from the database, professional knowledge of the participating specialists, and ample literature review. After review of the forms, the lead scientists in each country were personally interviewed by the final report team, while the interviewer cross-checked information from other countries and literature with the interviewed scientists. The acquired information was combined into new description forms.

Special attention was paid to aquatic ecosystems. For aquatic ecosystems, zoological information is of crucial importance, as it is the most visible part of open water systems. A few aquatic ecosystems, too small for mapping at the scale of 1:250,000, have been described as well, even though they may not actually appear on the map.

Climatic conditions

Important as local climatic conditions are, the UNESCO classification system only considers broad climatic zones like "tropical" and "temperate," with all Central American ecosystems defined as "tropical." However, the UNESCO system indirectly takes into account local climatic conditions through their effect on the physiognomic life form.

In addition, the UNESCO system includes altitude terms, which are effective proxies for climatic conditions because of the strong relationship between altitude and climate. As we have seen previously in the text on the Holdridge System, ecological conditions vary markedly with changes in elevation. Precipitation and humidity usually increase with elevation, though drainage is almost always good in the steep mountains of Central America. Furthermore, in regions with humidity deficits

at lower elevations there is usually a change in degree of seasonality as elevations increase, from deciduous or semi-deciduous to evergreen.

Other conditions that change with increased elevation are: lower atmospheric density; increased direct solar radiation, particularly ultraviolet (which may be offset by increased cloudiness); stronger winds; and fewer solar hours because of increased cloud cover. These elevation-related conditions require survival strategies such as increased tolerance to low temperatures, protective layers to reduce ultraviolet exposure, and dwarf life forms to protect against wind and seasonal desiccation.

The original UNESCO system defined the following altitudinal descriptors: Lowland, Submontane, Montane, Subalpine, and Cloud. However it did not define specific altitude ranges for them because the ranges vary by geographic region. The local climatic conditions in the mountainous regions of Central America are complex, and for the ecosystem classifications of the current map we needed to create a new zonation adapted specifically to Central America. Furthermore, the Atlantic and the Pacific regions vary somewhat in their climatic conditions, with the Atlantic region usually being cooler and wetter at any given altitude. Based on the personal experience of one member of the project team (Gómez), we agreed during the Las Cruces, Costa Rica workshop to adopt the altitudinal descriptors shown in Table 3. These probably need to be validated through further research.

Designating an area as being in the Atlantic or Pacific slope is sometimes arbitrary. The differences in zonation defined by slope orientation can often be observed on individual mountain ranges irrespective of their actual distance from the coast. The situation is even more complicated in Guatemala and Honduras, where there are blocks of inland mountains. The distinctions are clearest in Costa Rica and Panama, where both the countries and the mountain ranges are relatively narrow.

Table 3. Elevation Criteria for Ecosystem Classes

	Elevation (meters)	
Altitudinal descriptors	*Atlantic slope*	*Pacific slope*
Lowland (*Tierras bajas*)	0–500	0–700
Submontane (*Submontano*)	500–1,000	700–1,200
Lower montane (*Montano inferior*)	1,000–1,500	1,200–1,800
Upper montane (*Montano superior*)	1,500–2,000	1,800–2,300
Altimontane (*Altimontano*)	> 2,000	> 2,300

Seasonal change in the phenology of communities

A seasonal change in phenology is caused by partial or full shedding of foliage and by withering or other changes in the herbaceous layer. Seasonality may also result from prolonged seasonal flooding.

These changes are considered adaptations to climatic conditions of seasonal low temperatures or drought. Seasonal leaf shedding is considered a very important ecological phenomenon. Not only does it require that species be tolerant to dryer conditions, but organisms in a defoliated forest are also more exposed to direct solar radiation and higher temperatures.

Sets of species that can cope with such seasonal variation are different from those that live under continuously moist conditions. Species that can survive these conditions adapt mechanisms to get through the dry season, such as one-year life cycles, surviving underground tissues, seasonal hiding, and epidermal or skin desiccation protection.

The criteria mentioned in the UNESCO system for "seasonal evergreen tropical forests" are (a) bud protection and (b) partial foliage reduction during the dry season, often as partial shedding. Bud protection, typically an element of cold seasonality, was not the most visible characteristic of seasonal evergreen tropical forests in our region. In Central America seasonality is drought related, therefore tree species in seasonal evergreen tropical forests are often more drought resistant than those in nonseasonal tropical forests and they have adaptations such as hairy or leathery leaves and smaller leaf sizes (see also Gómez 1986b). There may be a tendency toward increased leaf shedding, but the overall aspect remains foliated throughout the season and this characteristic was not easily used as a criterion to classify seasonal forests. During the course of our field work it was noted, however, that seasonal forests could often be identified by withering of the herbaceous layer.

Leaf/plant morphology

The main categories recognized by UNESCO are broad-leaved, needle-leaved, microphyllous, palmate, bambusoid, graminoid, and phorbs. Predominant leaf morphology gives some information about ecological conditions, particularly in the context of other data. For example, needle-leaved forests are usually more fire resistant, and may give some indication of frequent burning. Species composition differs widely among broad-leaved, needle-leaved, microphyllous, and palmate forests. Most of the time, tropical forests are composed of a mix of trees of diverse leaf types, something not clearly reflected in the UNESCO classes.

Reflecting its temperate origins and economic orientation, the Central American forestry sector traditionally has distinguished between forests that are broad-leaved, needle-leaved, and mixed. The term "mixed" is normally reserved for mixed stands of broad-leaved and needle-leaved trees and does not take into consideration mixed stands of other leaf morphology categories. The UNESCO system follows this tradition, which is rather unfortunate because stands of other mixes of leaf morphology categories abound in the tropics (for example, broad-leaved/palmate, broad-leaved/graminoid, palmate/graminoid, broad-leaved/bambusoid, etc.). To maintain consistency with the widely accepted UNESCO system, the present study used the same definitions, but a future rethinking of categories may be desirable.

Drainage

Drainage is referred to frequently in the UNESCO system. For soil organisms and plants, poor drainage and flooded conditions require sophisticated mechanisms for gas exchange, escape from saturated or flooded conditions, or some form of seasonal dormancy. A huge variety of aquatic and semiaquatic organisms are adapted to seasonally flooded or poorly drained habitats.

In general, drainage was considered to be good in hilly or mountainous terrain and moderate in flat but noninundated terrain. Water-logged and flooded conditions were recorded in accordance with field observations and expert knowledge. At our working scale of 1:250,000 we have applied labels to large areas, so of course within areas classified as "well drained" there could also be poorly drained or swampy patches.

The situation is more complicated in areas with little or no inclination, which are mostly found in the lowlands. Some areas, in spite of the lack of inclination, should still be considered "well drained" when the soil type is appropriate. "Moderately drained" areas are occasionally wet or even waterlogged, but not flooded.

Many ecologists distinguish between swamps (woody communities) and marshes (herbaceous communities). Unfortunately the UNESCO system does not differentiate well between the two, and the terms swamp and marsh are both used for woody and herbaceous formations. Future revision of the use of these terms in the UNESCO system would be desirable.

In general, the Central American UNESCO classification is a bit more specific on drainage than the original UNESCO classification. For nonflooded forests, we added "moderately drained" as a distinction from "well-drained," but at the lowest level of the hierarchy. The original authors of the UNESCO system intentionally built in the flexibility to allow this kind of adaption.

Soils

At a scale of 1:250,000 soil classes can only be coarsely distinguished, so they contribute little information that is not implicitly defined by other ecological factors such as drainage and plant physiognomy. Therefore, as a rule the UNESCO classes are not expanded for soil classes. However, there are a few broad soil types that are known to be accompanied by specific sets or subsets of species and which can be valuable in an ecosystem classification.

The origin of soils sometimes gives an indication of their fertility. In Central America soils that originated from limestone (such as in karstic areas) and volcanic activity are usually more fertile than soils derived from other geologic formations. In principle, calcareous soils are relatively nutrient rich, chemically basic, well drained, and sometimes shallow. Such soils may contain different species sets from oxisols—deep, weathered, acidic soils typical of tropical rain forests. However, in the humid tropics weathering, leaching, and humus accumulation may strongly neutralize the effects of the original material. Generally we found that calcareous soils or rocks provided a sufficient basis for distinguishing distinct ecosystems. Therefore, calcareous soils are a distinguishing criterion in several classes as well as "poor or sandy soils" in one class in Belize.

Another important soil formation is peat. Often formed with sphagnum, peat formations usually contain very different species sets that are tolerant of prolonged inundation, low nutrient availability, and high acidity. On the border of Costa Rica and Panama there are some very interesting "tall sedge swamps" with sphagnum. The peat formation is not explicit in the nomenclature but it is mentioned in the descriptions.

Several other soil formations—such as recent sandy soils, certain clay formations, and recent volcanic soils—may be promising as ecosystem class indicators. These were not used on the current map but could be worth including in a revised map or an extension of the map to a finer scale.

Salinity

Communities with elevated levels of salinity are listed separately. These exist primarily, but not exclusively, in coastal environments. Species resistant to elevated salt conditions are relatively scarce and many grow exclusively under saline conditions. In the humid tropics woody life forms dominate saline coastal environments, with mangroves being the most common formations. Saline savanna types are less common. Examples of classes we defined in which salinity is particularly important are "salt meadow poor in succulents" (VE1a(2)) and "marine salt marsh rich in succulents" (VE1a(1)).

Unvegetated areas

Bare land surface conditions are rare in Central America, but we have included classifications for "scarcely vegetated lava flow" and "scarcely vegetated scree" in formation class VI. The original UNESCO classification did not explicitly subdivide formation VI into deserts and scarcely vegetated areas. In addition, scarcely vegetated areas also occur as extended bare mudflats in the southern part of the Golfo de Fonseca and on a smaller scale in Azuero in Panama. We identified these areas as "salt meadows poor in succulents," except when we didn't map them because they were intertidal or too small. Marine rocks and nonvegetated islets were classified in this formation class as "scarcely vegetated marine rocks" (V1Ae).

Natural ecosystems versus productive systems

This map in principle deals with natural ecosystems. However, virtually all natural habitats in Central America are occupied by or used by people to some extent and it is often difficult to distinguish between natural habitats and converted habitats.

The UNESCO system is designed to be used for both natural and intervened vegetation structures. It does not explicitly distinguish natural habitat from human intervened habitats. One may perfectly describe an oil palm plantation in Honduras with a UNESCO code. Given our intention that the ecosystem map be useful for biodiversity conservation purposes, we only used our system to define natural habitats. However, at the lowest (most detailed) level of the classification hierarchy we did incorporate descriptors to provide information on the relative degree of human intervention.

We originally started with "natural" versus "modified," but feedback from field use led us to recognize three classes of disturbance for modified ecosystems, with class one representing the least intervention. These classes are detailed in the "Central American Ecosystems Monitoring Database Manual" (available on the World Bank web site). For field relevés this degree of detail is feasible, but for the mapping we reduced the levels of intervention to "moderately intervened" (which corresponds to class 1 from the manual), and "intervened" (which corresponds to classes 2 and 3).

The classification of anthropogenic influence is very complex and bound to be subjective. For example, much of the coastal plains of Belize and the Mosquitia in Honduras and Nicaragua are burned every few years if not annually. This suppresses forest growth to some degree, but with little or no grazing in these areas the vegetation has a strong natural appearance and reestablishes itself spontaneously after the fires. Such cases suggest a designation of class 1 intervention, while in areas with moderate grazing class 2 seems more appropriate. Many spontaneously seeded Caribbean Pine stands in Belize and the Mosquitia are managed as production forests through thinning and selective logging. Still, these forests maintain well-developed shrub and vegetation covers and maintain distinct natural characteristics. Under such conditions class 3 might seem appropriate. The national experts followed broad guidelines from the database manual to classify the degree of intervention, but there may be variation from country to country in interpreting and applying the terms to specific cases.

Aquatic Ecosystems

Although the UNESCO system is usually considered to predominantly cover terrestrial formations, it does include vegetated aquatic ecosystems. Within formation classes I–VI terms such as "flooded," "riparian," and "waterlogged," are used to describe ecosystems that are wet or covered with water on a periodic or temporary basis, or even constantly in the case of certain swamp formations. These ecosystems include bogs, flushes, salt marshes, flood savannas, sedge swamps, and numerous other variations.

In addition, formation class VII, Aquatic Plant Formations, encompasses systems in which water covers the soils constantly or at most times of the year. This formation class includes five formation subclasses:

- Floating meadows
- Reed swamps
- Rooted floating-leaf communities
- Rooted underwater communities[4]
- Free-floating freshwater communities

Each of these formations has a distinct set of species that usually occupies different niches of an aquatic system depending on water clarity, depth, flow velocity, etc. Several formations may occur within a short distance of each other, and in many cases they are not mappable at a scale of 1:250,000.

The project team considered a variety of existing classification systems (including Gómez 1984, 1986c; Green et al. 2000) but finally we determined that the original UNESCO system categories were adequate to describe aquatic ecosystems with a distinguishable vegetation cover above or under the water surface. We did however add information at the end of the class for floristic and/or geographic detail.

4. In this category we include marine seagrass and algae beds.

Open Water Formations (VIII)

Open water ecosystems without a substantial vegetation cover are the only formation in Central America not encompassed by the UNESCO system. Therefore we created formation class VIII, "Open Water Formations." Open water formations are predominantly covered by water and have less than 10 percent of their area covered by emergent, floating, or submerged vegetation. In the legend, the formation class VIII ecosystems are coded as "SA" for "sistema aquatica," but these should eventually be recoded as VIII.

In developing criteria to use within this class to further distinguish ecosystem types, we determined that salinity was the most important characteristic. Most marine species are separated from limnic (freshwater) species merely by higher concentrations of salt. Some species are adapted to switching back and forth between saline and freshwater systems. However, the species sets for limnic, brackish, and marine systems are for the most part clearly distinct and therefore the degree of salinity is considered the single most distinctive factor for aquatic ecosystems. In the new formation class, the proposed subclasses are:

- Limnic (freshwater) ecosystems
- Brackish ecosystems
- Marine ecosystems
- Saline lakes and closed seas (absent in Central America)

Limnic or freshwater systems

These are inland systems, typically rivers, lakes, and swamps. Wooded swamps usually fall under formations I, V, or VII. Lakes often have fringes of emerged vegetation that are classified under formations V or VII.

Limnic open water systems lack major areas of aquatic vegetation that would allow their classification under the UNESCO system. It is possible that in the future, fish distribution patterns could provide information to distinguish open water ecosystem classes (see the recommendations in Section 5).

Brackish systems

This subclass includes estuaries—aquatic systems of varying salinity that usually are highly dynamic. Estuaries often have high sedimentation, low transparency, and low species diversity, but high organic productivity. In Central America most estuarine mud banks are covered with mangroves (IA5). If the bare mud flats are extensive enough, they would be classifed under category VIB3, "Bare intertidal mud flats."

A distinction was made on our map between semi-closed and open estuaries. In retrospect however, there is perhaps no clear ecological reason for maintaining this distinction.

Marine ecosystems

In the context of this work, marine habitats (that is, areas that are below the tidal line and permanently under water) are split into littoral systems (to a depth of 50 meters) and pelagic systems (deeper than 50 meters).[5] As the term is traditionally used, littoral systems also encompass tidal zones, which may include beaches, salt marshes, and mangroves—habitats we place under classes V to VII.

Within the littoral zone, sea floors may be rocky, silty, sandy, or gravelly. While these characteristics could be used as classification criteria, we did not use them at the 1:250,000 scale of this study. Some areas will have greater than 10 percent vegetation coverage and therefore would not be included in class VIII (although in practice, most are so small they cannot be mapped except at fine scales). In particular, areas of sea grass are classified by us as VIID2a, "Submerged marine fixed forbs." Sessile marine macroalgae often occur among corals (although they are usually much less important than corals in coverage) and at times may be important enough to be mapped as VIID2b, "Submerged marine fixed macroalgae" (perhaps further distinctions will eventually be needed to reflect relative presence of coral in these ecosystems).

Sometimes, extended water bottoms may be covered with algae. This may occur in both fresh and marine waters as well as in tidal zones. However, often such conditions are seasonal and short-lived. Particularly in temperate climates, such algae may become buoyant, free-floating vegetation. In marine areas these could be mapped as VIID2c, "Submerged marine fixed microalgae." Marine algae growth is often considered an indication of environmental stress, and like "coral bleaching" it could function as an important sign of ecosystem health.

In the course of the mapping project, coral formations were considered and research was undertaken but ultimately they were not mapped, except in Belize. This was partially due to an uncertainty about our methodological approach and partially due to the limited availability of specialists from the region at the time.

5. At depths greater than 50 meters, biological diversity rapidly decreases. This depth is also a very practical dividing line for the purposes of the ecomapping project because it is often marked on bathyometric maps and is about the maximum depth that scuba divers can descend without specialized equipment.

However, these ecosystems are vital and inseparable parts of the biodiversity of the region and of each country where they occur. We strongly urge that this be revisited in future mapping efforts (see recommendations in Section 5).

2.3 Data Collection

Acquisition of Satellite Imagery

Ecosystem (or vegetation) mapping has always depended on a bird's eye view of the landscape. Until the end of the 1980s, vegetation mapping was almost exclusively done on the basis of aerial photographs taken at a 90-degree angle from an airplane. Rarely were aerial photographs taken for the purpose of vegetation mapping; usually vegetation mapping projects depended on existing photographs taken for topographic mapping and/or military purposes. This dependency limited vegetation mapping because the material was often old or classified.

Aerial photographs are the most accurate "overhead imagery" for ecosystem mapping. They can visualize vegetation structure better. Typical characteristics like tree cover, plant morphology, and plant distribution can best be seen from aerial photographs. With the use of a stereoscope, it is possible to view the structures in stereo and even measure canopy height and directly identify some species. They can be taken as black-and-white photos or as color photos, the former being sharper and the latter showing additional color-based information.

The interpretation of color photographs is, however, extremely labor intensive. Their acquisition is very costly and in some regions practically impossible because of extremely frequent cloud cover, as in the Talamanca Mountains and the Darién. Obtaining complete recent sets for seven countries would be close to impossible because of the cost involved and the organizational requirements to completely photograph the territory of these seven different countries from an airplane. The interpretation of the photographs would have required several years. This approach is being used very successfully in Costa Rica by INBio for the 1:50,000 scale ECOMAPAS initiative, but it will take many years to map the whole country.

Serious vegetation mapping from satellite images did not become a practical option until reasonably fine-scaled panchromatic images became widely available in the late 1980s. Panchromatic satellite images do not show actual structure (physiognomy), rather they show differences in geomorphologic structure and mosaic structure between vegetation types, which allows for physiognomic interpretation and distribution of recognized habitats. Freely available AVHRR images are panchromatic and may be used for delineating forested areas, however their spatial resolution is too coarse for the level of detail envisioned by this mapping project. They may be a useful complement to other imagery for the purpose of analyzing seasonality, but that has not been tried during this project.

In Central America, Landsat thematic mapper (TM) images are the most commonly used data source for mapping large areas. The Landsat satellites circle the Earth in predefined, numbered paths and take overlapping photographs that can be used to create a mosaic of satellite images. In traditional photographs the focused light activates photosensitive chemicals that color the film. The finer the grain of those chemicals, the sharper the pictures one can take. Similarly, satellites take digital "photographs" by registering the sunlight reflected by the surface of the Earth onto a fine raster of blocks, or pixels. To facilitate more diverse interpretation possibilities, the light is recorded simultaneously in seven different bands, thus creating seven "photographs" with different spectral reflection characteristics for a single "scene" in the Landsat grid. Separating the reflected sunlight makes it possible to distinguish color variations that would go unnoticed in a regular picture based on mixed-pattern light. Images prepared with band combination 4, 5, 3, strongly enhance the recognition of woody formations, which are shown in different shades of brown, while herbaceous formations are shown in shades of green; scarcely covered soils (plowed fields) may show in bluish shades or be very dark (lava streams and bare rocks).

During the previous mapping projects for Belize and Honduras at the chosen target resolution of 1:250,000, the imagery of the Landsat 5 TM, with a pixel size of 30 meters by 30 meters, proved to have the right detail for a reasonable compromise between acceptable ecological accuracy and the required production time of about one year. Landsat 7 TM imagery actually allows for mapping at a scale of 1:100,000 (Carignan, pers. comm., 1999). However, given budgetary and time restrictions, together with the availability of many additional paper maps at the scale of 1:250,000, we felt that choosing a level of detail that differs so greatly from existing topographic maps of the region would put the project at risk.

In term of cost, the Landsat 5 TM images had a major advantage: as a contribution to disaster relief the USGS had already made a set of images available that covered Belize, Guatemala, El Salvador, Honduras, and Nicaragua. This considerably reduced the purchase costs of the imagery. For Costa Rica and Panama some images were provided by the governments and some from the private collection of D. Muchoney. Where necessary we purchased additional images. We used the

following criteria to evaluate whether to use the images provided:

- Date of the image
- Spatial and spectral resolution
- Location accuracy
- Atmospheric conditions (clouds, haze)

Ultimately we needed to purchase only about one-quarter of the 39 images required to cover Central America. Given the cost-free availability of most of the images, and the satisfactory results obtained using the Landsat 5 TM in previous mapping projects, other image products, such as SPOT, were not taken into consideration.

Laser satellite images are not based on light reflection, and therefore are not hindered by cloud cover. They show differences in elevation and sharp demarcations of deforestation can be recognized. Because they are not light-based they can't show reflected colors, which is a major limitation. Laser satellite images with a resolution of 5 meters or more are not yet known to actually show sufficient vegetation structure, but laser images taken from an airplane, have been prepared by NASA to show individual tree structure. The CCAD/NASA project is experimenting with such images but imagery of this nature is not yet available for the entire region. At the time of the initiation of the project, these materials were still highly experimental, and therefore not considered although this technology seems promising.

For Belize, Guatemala, El Salvador, Honduras, and Panama, the imagery was processed in band combination 4, 5, 3, which allows for the strongest contrast between forested land (shades of orange-brown) and nonforested land (shades of green). In retrospect, we consider this to have been the most useful approach, although at the request of the lead scientists in Nicaragua and Costa Rica band combination 5, 4, 3 (mostly shades of green) was mainly used for those countries.

Green et al. (2000) conclude that satellite imagery is not well suited to detailed mapping of aquatic habitats, noting that satellite imagery is more appropriate for studying reef geomorphology than reef biology. The combined spatial and spectral resolutions of satellite sensors were not capable of reliably distinguishing between many habitats that had a high degree of similarity (Bray-Curtis Similarity, 60–80 percent). This was borne out by the high variability in accuracy associated with individual habitat classes. The poor separability of spectra rendered the supervised classification unable to assign pixels to appropriate habitat classes and resulted in large and variable allocation errors. It must be kept in mind that mapping with fine descriptive resolution is an ambitious objective: some biologically different reef habitats look similar even to the field surveyor underwater and can only be reliably distinguished by statistical analyses of species lists.

Acquisition of Auxiliary Data

In each country, the most relevant institutions were visited for auxiliary information (Table 4). Various institutions had useful digitized or paper map information, but it proved very challenging to actually obtain this information.

We acquired complete sets of topographic maps at a scale of 1:250,000 in each country, except Costa Rica where the scale was 1:200,000. In many countries full or partial sets were acquired at a scale of 1:50,000. The project acquired the aviation and navigation map sets of the USGS at 1:500,000 for the entire region. These materials were left with the participating institutions of each country.

In principle, additional digital auxiliary information is available from a variety of sources. Basic topographic data like roads, cities, national shorelines, etc. may be obtained in digital format from the USGS (as a Digital Elevation Model), as well as from national geographic institutions and some national GIS laboratories. However we found that the available Landsat imagery and scanned topographic maps provided much better precision, and therefore we used them instead. General soil data from FAO's global inventories in the 1970s should be available for each country, but were not always found.

Obviously, past vegetation mapping efforts, with or without the use of remote sensing techniques, are very relevant information sources as well. However, as valuable as those data and maps are for providing a historic perspective, in most cases they resulted from extrapolations of overland transects. Also, their level of detail normally did not approach the level of the current map, and seemingly equivalent systems from broad descriptions are likely to incorporate several classes of the current map, and therefore their distribution and size are usually not comparable to the current map. Notable exceptions to all of the above are the natural vegetation cover maps by Wright et al. (1959) and Gómez (1986), which are highly detailed and are based on walkovers and aerial photographs.

In addition, different sets of auxiliary data/maps were used in each country based on availability and usefulness to the national teams in terms of incorporating ecological or physical data as additional determinants of ecosystems. In most countries these included precipitation maps, temperature maps, geological maps, and various soil maps.

Table 4. Institutions Consulted

Country	*Institution*
Belize	Forest Department
	Programme for Belize
	Land Information Center
	WICE - Belize
	Belize Environmental Consultancies
	Wildlife Conservation Society biodiversity database
	Environmental, Social, and Technical Assistance Project
	Fisheries Department
Guatemala	INAB
	Instituto Geográfico Nacional
	Universidad de San Carlos
El Salvador	MARN
	Escuela de Biología, Universidad de El Salvador
Honduras	Departamento de Áreas Protegidas y Vida Silvestre
	Universidad Nacional Autónoma
Nicaragua	Ministerio de Ambiente y Recursos Naturales
	Instituto Nicaragüense de Estudios Territoriales (INETER)
	Universidad Centroamericana
Costa Rica	For Costa Rica the project was an updating of a mapping effort of many years. In this context many institutions have been consulted over the years.
Panama	Instituto Geográfico Nacional Tommy Guardia
	Smithsonian Tropical Research Institute
	Herbarium of the Biblioteca Simón Bolívar de la Universidad de Panamá
	Biblioteca de la Asociación Nacional para la Conservación de la Naturaleza (ANCON)
	Autoridad Nacional del Ambiente (ANAM)
	Autoridad del Canal de Panamá
	Library of the Empresa de Transmisión Eléctrica (ETESA)
	Library of the Instituto Comemorativo Gorgas
	Library of the Departamento de Gestión Ambiental de la Autoridad de la Región Interoceánica (ARI)
	International Training Center (ITC)
Netherlands	Hugo de Vries Laboratory of the University of Amsterdam
	Library of the Agricultural University of Wageningen
	Library of the Faculty of Plant Systematics of the University of Utrecht
United States	Library of Conservation International
	Library of the IUCN
	Library of the WWF

Selection and Adaptation of Boston University Database

An ecosystem map presents sharply defined polygons with authoritative labels. However, any classification system is arbitrary in the sense it reflects all the biases of its authors as well as all the imperfections and errors inherent to any map and to any classfication system.

It has been convincingly argued by Douglas Muchoney and others that in a sense, the most useful data are in fact not the maps but the field data for individual field verification points. These data consist of fairly objective descriptors of the ecological and physical characteristics of the site. If these data are appropriately defined, collected, and stored, they should allow the user to in effect bypass the need for a previously defined "ecosystem map" and instead generate a map taking into account whatever characteristics are of interest.

For this reason, use of a field data database was considered to be an extremely important part of this project. About 2,000 field data points were collected (see below) and we believe that this database does in fact constitute an extremely important underpinning of the ecosystem map and, if maintained and expanded, it should ultimately replace the need for a static map.

Incompatibility of data registration (classes used, methods of data collection applied, etc.) is a huge problem in data exchange—much bigger than the problem caused by incompatibility of the software used to store those data. The project dedicated great effort to deciding which field information to collect. We started out with the "STEP" design of the University of Boston (Muchoney et al. 1998) and tested it extensively with the participating scientists in the field. Renowned external international scientists were consulted (Professor R.A.A. Oldeman, Ph.D., University of Wageningen; Professor A. Cleef, Ph.D., University of Amsterdam; and Dr. H. van Gils, International Training Centre).

Feedback from almost all the participating and consulted scientists ultimately resulted in modification of the database. From the STEP model we maintained the terrestrial landscape parameters for analysis of high spatial resolution remote sensing data (Landsat TM, MSS, and SPOT) as well as data for regional and global characterization using moderate resolution data such as AVHRR, MODIS, and SPOT-Vegetation. For that purpose, it includes many new fields for important ecological, biogeophysical, and population parameters that can be reliably measured or inferred from remote sensing, collateral, and relevé data. Furthermore, the STEP method provided the foundation for systematic field parameterization and GIS compatibility. The data set allowed us to efficiently characterize any ecosystem class—terrestrial or aquatic—within the region.

Field Verification

Fieldwork is the heart of a mapping project. The mapmaker must know and understand what is to be shown on the map. For the current mapping project this knowledge came from the many years of field experience of each participating scientist. They were able to analyze remotely sensed images and make a very reasonable first assessment of the ecosystem type in the different parts of the country. This allowed them to draw polygons on the printed images or on the computer screen and classify them. It also required them to systematize their knowledge, because it showed which areas they knew well and which areas were virtually unknown.

Relevé selection

Theoretically, if one chooses the field sites or relevés at random, eventually enough records will provide a statistically correct classification. However, fieldwork is the most expensive and the most difficult activity to organize in an ecosystem mapping project. The random sampling approach requires a great number of samples of each polygon type and in general is far too expensive and time consuming. This approach was followed by the Honduran team, but in all the other countries the national teams chose to use a directed preselection of areas for field visits.

In general, relevé samples were selected on the following criteria:

- Insufficient expert knowledge of the region
- Doubt about the classification on the image
- Representativity (preferably each recognized class was visited at three different locations)
- Irregularities observed from the air
- Accessibility
- Opportunism[6]
- Time and cost considerations (traveling by road is usually much more economical than traveling over water or by helicopter, and much faster than traveling by foot)

The data collected and on-site methodology are described in the Database Manual, available on the World Bank web site. Both the size and the shape of the relevés were designed for a relatively rapid field analysis. In all the countries except Nicaragua we used a circle with a 25-meter radius (area of about 1,960 square meters). In Nicaragua, 25-meter by 200-meter rectangular plots (5,000 square meters) were used. Surveyors were instructed to enter well inside the area that the polygon represented, seeking conditions representative of that polygon and of that ecosystem class. GPS readings were taken with Garmin 12 GPS units without a base station to correct the intentional errors introduced by NASA in 1990. Without correction of these errors, these units have an accuracy of 100 meters in the open, although readings taken at known positions were often more accurate. In forests, readings are much less accurate or impossible. When no reading was possible, one was taken at the nearest clearing and from there positions were estimated on foot.

The teams were instructed to mostly focus on woody species and spend no more than two hours at a relevé. Unknown tree species were sampled and identified afterwards, usually in a national herbarium. In the region as a whole, several thousand samples were collected and conserved in the national herbaria and in many cases have resulted in range extensions and even some new reports for some countries.

Field trips were undertaken in four-wheel-drive vehicles. In Honduras and Nicaragua, areas of difficult access were sampled from a helicopter and by boat.

Data registration

Paper field forms were developed so that the general relevé data fits on one page, while the species information fits on the back of the same page, thus keeping all information together. This avoids the risk of later mixing up the data.

The field form is the field version or paper copy of the database that stores the field observations systematically and allows for further analysis. The data of the field forms are stored in a user-friendly Microsoft Access database. The field form and the database can be downloaded from "http://www.worldbank.org/ca-env". By formalizing the data in the database in harmony with the GIS of the ecosystems map, users can use both database and GIS software to extract information on sites of particular interest. The data in the database can be used without the GIS program.

Aerial surveys

Aerial surveys are an integral part of the ecosystem mapping process. Flights were planned to cover all major preidentified polygon classes, areas of difficult access, and areas poorly known by the participating scientists. In each country aerial surveys were carried out from small fixed-wing aircraft, usually at an elevation of approximately 300 meters. Airspeed was usually between 175 and 210 kilometers per hour, depending on the plane

6. For example, the Armed Forces of Honduras occasionally offered helicopter transportation in exchange for the cost of the fuel.

and the weather conditions. Whenever specific details needed to be examined, the plane was taken to a lower elevation.

Usually the flights were carried out by the lead botanists and the lead image analysts (often the same person). The Technical Coordinator, Daan Vreugdenhil, participated in several of the flights over each country except Costa Rica and El Salvador. His participation in flight programs of all but two of the participating countries allowed for standarization of the approach used between countries. Table 5 shows the total flight hours and lead participants in each country. Not all surveyors participated in all of the flights in his/her country.

In most countries, oblique photographs were taken of sites of interest, but often is was not possible to establish precise GPS positions from the plane. Usually photographs were taken without GPS readings, and were located on the topographic maps. In Panama the team installed a video recorder in the back of the airplane, which recorded the landscape sideways while taking real-time GPS positions. This turned out to be an extremely useful method. Vegetation structure analysis could be clearly visualized while playing the tapes back on a television screen. Originally most teams thought that performing verification flights from fixed-wing airplanes would not be ideal, but after the program was finished there was general consensus that this is a very realistic approach in which the benefits outweigh the costs.

Table 5. Field Verification Flights

Country	*Lead participants*	*Total hours of flight*
Belize	Susan Iremonger Jan Meerman Daan Vreugdenhil	16
Guatemala	Cesar Castañeda Juan José Castillo Mauricio Castro Daan Vreugdenhil	20
El Salvador	Raúl Villacorta Nohemi Ventura	5
Honduras	Susan Iremonger Daan Vreugdenhil Carlos Serrato Thelma Mejía Cristóbal Vasquez	22
Nicaragua	Alain Meyrat Daan Vreugdenhil Alfredo Grijalva	16
Costa Rica	Luis Diego Gómez	8
Panama	María Stapf Boris Gómez Daan Vreugdenhil	15

In Honduras and Nicaragua both helicopters and fixed-wing planes were used in a combined effort of air verification and logistics for relevé analysis in highly inaccessible locations.

2.4 Data Processing

Preparation of Base Maps

Early in the project we decided to follow the scale of each country's intermediate-size topographic maps: 1:250,000 for Belize, Guatemala, El Salvador, Honduras, Nicaragua, and Panama, and 1:200,000 for Costa Rica. Each country used their own national projection standards, which differ from country to country.

Although basic georeferencing was originally provided for many images, in each country more precise georeferencing was required for synchronization with other images and the topographic maps. Metadata provided with the map files gives more detailed technical information.

An additional set of imagery has been prepared in Projection UTM, Zone 15, Elipsoide Clarke 1866, Datum Nad 27, bands 4, 5, 3, so that advanced users can project the entire map against a background of imagery used in the project. Georeferencing consisted basically of choosing reference points in the image (crossroads, fixed river curves, and coastal rocks, etc.) and defining a first-grade polynomial regression line for optimizing the scene adjustment. Between 15 and 20 evenly distributed reference point were used for each scene.

Digitization of Polygons

It is possible to make maps directly on a computer screen by precisely digitizing lines on top of an image. However, standard computer screens are still relatively small and don't allow for a detailed view of an image in its totality, which is often desirable for interpretation purposes. An experienced image analyst can also have computer software distinguish between similarities in the patterns of pixels and thus come up with a computer-generated distinction of classes: a "supervised classification."

However, experienced vegetation analysts (van Gils, pers. comm.; Iremonger 1997, and pers. comm.) expressed their doubts about the accuracy of such a method for detailed mapping. They feared that many classes would show up in highly mixed, "pepper-and-salt" mosaics, where human interpretation would still be required to choose the shape of polygons and their classification.[7] Supervised classification of ecosystems has not been used in this project because it was not expected to provide the required level of accuracy.

The project has attempted to involve as broad a group of scientists as possible from the universities and institutions of the participating countries. It facilitated the participation of both GIS and non-GIS trained scientists by primarily working from satellite images printed at a scale of 1:250,000 on 36-by-36-inch sheets. At this size, several scientists could work at an image simultaneously, thereby allowing joint analysis and stimulating scientific dialogue and exchange of experiences (without the barrier often posed by different levels of computer skills between a GIS specialist and a field biologist). The use of printed images has strongly stimulated the interest and involvement of a multitude of scientists. As people started to learn and appreciate the use of images, their desire to become involved in further computer analysis often increased as well. Some participants have acquired on-screen mapping skills; a few have also worked with supervised classification. Nonetheless, the primary mapping exercise has taken place on the basis of the analysis of printed images involving field biologists, most of whom have more than 15 years of pertinent field experience. In El Salvador, image analysis was done directly on-screen.

The acquired images allowed the identification of more or less homogeneous landscape patches, which can be mapped as polygons on transparent material like mylar paper or acetate. Mylar paper does not change size with temperature, but is poorly transparent. Acetate is highly transparent but expands with raising temperature. Temperatures rise while drawing with a warm hand and when the image is analyzed with lamps from under a light table. We found that the benefits of the higher transparency of acetate outweighed the minor expansion at higher temperatures. In Costa Rica in contrast, mostly mylar paper was used. In many cases, the images were illuminated both from overhead light and from transparent light tables.

Some analysts suggest working directly on plastified prints, but since various images are required for the overlapping edges and topographic maps are required for elevation lines, transparencies are needed to transfer the delineated polygons from one source (the image) to another (the topographic and thematic maps). Working directly on the printed paper should be avoided because it does not allow for erasing and correction.

More or less homogeneous units (polygons) were drawn by hand on the acetates with the finest available markers (waterproof, alcohol dissoluble). For reasons of scale (1:250,000) and legibility, areas smaller than 150 hectares usually are not represented on the final map. After the polygons were initially drawn on the basis of the satellite imagery, additional ecosystem polygons were identified and/or adjusted with the help of auxiliary information, field analysis, and reconnaissance flights.

After the hand-drawn acetate maps were finished they were digitized using various software programs. Final map files were the produced through a reiterative process of field visits, reconnaissance flights, and reexamination of images, adaptations to the GIS files on top of images, and the hand-drawn acetate maps. Where necessary, files were converted into ArcView shape files.

Integration into One Regional Map

The following section on the integration of the data into one regional map is based on text contributed by Dr. Jeffrey Jones, Director of the GIS Laboratory of CATIE.

The processing carried out in CATIE's GIS Laboratory was divided into four distinct activities:

1) Image importation and registration
2) Integration of country vector layers
3) Establishment of a common projection
4) Creation of the 1:250,000 map set

Image importation and registration

A set of qualifying images covering the Central American Isthmus was selected from the collection of 161 images on CD-ROMs provided by the project participants. In some cases, an additional image was needed when the one for a given area suffered from cloud cover. Each image was registered directly from topographic maps. In many cases 1:50,000 scale topographic sheets from the CATIE laboratory archives were used, and if these were unavailable, 1:500,000 aeronautical navigation charts for the region were used.

The purpose of this activity was twofold. First, the set of images was documented for the purpose of making them available to the Central American research community for future mapping work. The second objective of the image registration activity was the creation of country image sets to be distributed with the final Ecosystem Map product, on CD-ROM. For this activity to be feasible, images were degraded to a resolution of 240 meters per pixel, so the completed mosaics were between 20MB and 80MB each. While these degraded images lack resolution, they provide a guide and backdrop for viewing the completed ecosystem files, which helps knowledgeable researchers orient themselves.

7. "Polygons" are spatial map units with specified color and texture that differentiate them from adjacent map units.

Table 6. GIS Software Programs Used

Country	*Image processing*	*Digitizing*
Belize	ERDAS	ArcView
Guatemala	PCI	ArcView
El Salvador	ILWIS	ILWIS
Honduras	ERDAS	ArcInfo
Nicaragua	PCI, ERDAS	ArcView
Costa Rica	ILWIS	ILWIS
Panama	PCI	ArcView

Integration of country vector layers

Because most national map files were handed over as ArcView shapefiles, problems of data translation were minimal. Only Costa Rica and El Salvador were originally digitized in ILWIS, but the file transformation caused no problems. Problems with integrating the layers were of a different nature:

1) Coordinating legends from the different countries
2) Converting semidocumented projections to a common projection
3) Making borders compatible in terms of national limits and the continuity of vegetation

Coordinating legends

At the initiation of the project, before the involvement of CATIE, all country teams agreed on a methodology for describing ecosystems. This method was based on the UNESCO classification. The UNESCO classification, being a hierarchical system, allows the possibility of adding categories as needed. However, as a result, each country could introduce new categories of vegetation according to their own needs. Therefore, despite considerable efforts to coordinate work between countries, each country map had an independent legend. The legends had some common elements, but also had some unique classes that were distinct from those of neighboring countries. These issues were addressed at the November 2000 meeting in Managua.

After November 2000, all country-specific editing of legends was done directly on the regional map. Polygons were altered, codes were modified, and legend categories were subdivided, but only on the regional map. If a new category was developed for a specific country, the original country map was not updated. This is mentioned to explain the possibility of inconsistencies between the completed regional map, the final country maps derived from the regional map, and the national maps.

Converting semidocumented projections to a common projection

In Central America, each country has developed its own official projection. These projections are officially presented on the cartographic map sets of each country.

In recent years there have been changes in the cartographic systems of the countries, with the introduction of new map sets with slight variations in projection details. In most cases, the country teams insufficiently documented the projections used.

As a result, the final adjustment and conversion of the national ecosystem maps to the regional projection, and the coordination of national borders in adjacent countries required a certain amount of research and testing to achieve the best and most consistent fit of data. It should be noted that the typical error encountered in these adjustments was between 200 and 500 meters, errors quite typical of a 1:250,000 map set. While these values in a broad sense were marginally acceptable on their own, when juxtaposed with the adjacent country polygons and borders, the errors became quite visible.

Making borders compatible in terms of national limits and the continuity of vegetation

Another challenge involving in the integration of the national maps was the creation of compatible/acceptable border definitions. This problem has two elements: the location of the border itself, and the continuity of vegetation patterns from one side of the border to the other.

In the case of the locations of borders, final editing was done to resolve more obvious errors, which in many cases were simply questions of which year a river edge was marked as a border. For example, if a river meander moved in its course, and the adjacent countries used river edges from different years, then an "error" appeared even though the actual location of the border was clear. In the case of Guatemala and Belize, sandbars appearing in the Sarstun River were mapped as part of both countries. In some countries, border disputes created

Table 7. Projections Used in Ecosystem Mapping

Country	*Projection*
Belize	UTM 16, NAD27 derived datum
Guatemala	UTM 15, NAD27 derived datum
El Salvador	Lambert, NAD27 derived datum
Honduras	UTM 16, NAD27 derived datum
Nicaragua	UTM 16, NAD27 derived datum
Costa Rica	Lambert, Ocotepeque datum
Panama	UTM 17, NAD27 derived datum

areas where the definition of national boundaries was problematic. The regional map of Central America was used as an arbiter wherever possible, although in the end a simple line was often drawn indicative of the border zone.

It goes without saying that the zone of the indicative border between countries has not been done in this project with the intention of supporting one or the other territorial claim, and does not indicate acceptance or support by CATIE, CCAD, or the World Bank of any specific claim.

Problems of discontinuities of vegetation arose due to the use of images with cloud cover or images from different dates in adjacent countries. Areas with cloud cover are interpreted on the best available information and the interpretation of the country team. Originally, the integration of vegetation boundaries along the borders was carried out in consultation between teams of the concerned countries. The resulting integrated map was printed by MARENA for a regional meeting in Managua, Nicaragua, in November 2000, when the different country teams met to agree on consistent boundaries and polygon nomenclature. Once these corrections were agreed on, the regional and national maps were edited to reflect the changes.

Establishment of a common projection for the Regional Ecosystems Map

The creation of the Regional Ecosystem Map required us to confront a long-standing problem for the Central American Isthmus and the process of Central American integration. If the region is to be presented in a single map, what map projection should be used?

Map projections are transformations of data from the spherical earth to flat paper, a process that inevitably introduces distortions. Selecting a map projection depends on the objectives of the final map and an evaluation of which particular distortion is most acceptable. In the case of the Ecosystem Map, it was determined that the most critical criterion for selection of the projection is that it be "equal area," which is to say that it minimizes distortion in areas between different parts of the map. This characteristic would permit comparison of the size of different ecosystems between countries to determining how many hectares of each particular ecosystem existed, how many were protected, and in which countries.

In October 2000 a formal request for input was circulated to the heads of the geographic institutes in the seven countries. A number of suggestions were made, including the use of the projection defined by the Instituto Panamericano de Geografía e Historia (IPGH) in the recent regional map. Unfortunately, in the opinion of the president of the Central American IPGH group during the creation of the regional map, use of that projection without express permission of IPGH would not be advisable.

The projection finally selected was a Lambert Azimuthal, centered at 85° west longitude and 13° north latitude, in the geographic center of Central America (this point is actually inside Nicaragua). To maintain all coordinates as positive, an offset of 5 million meters was incorporated as a false easting and a false northing.

Creation of the 1:250,000 map set

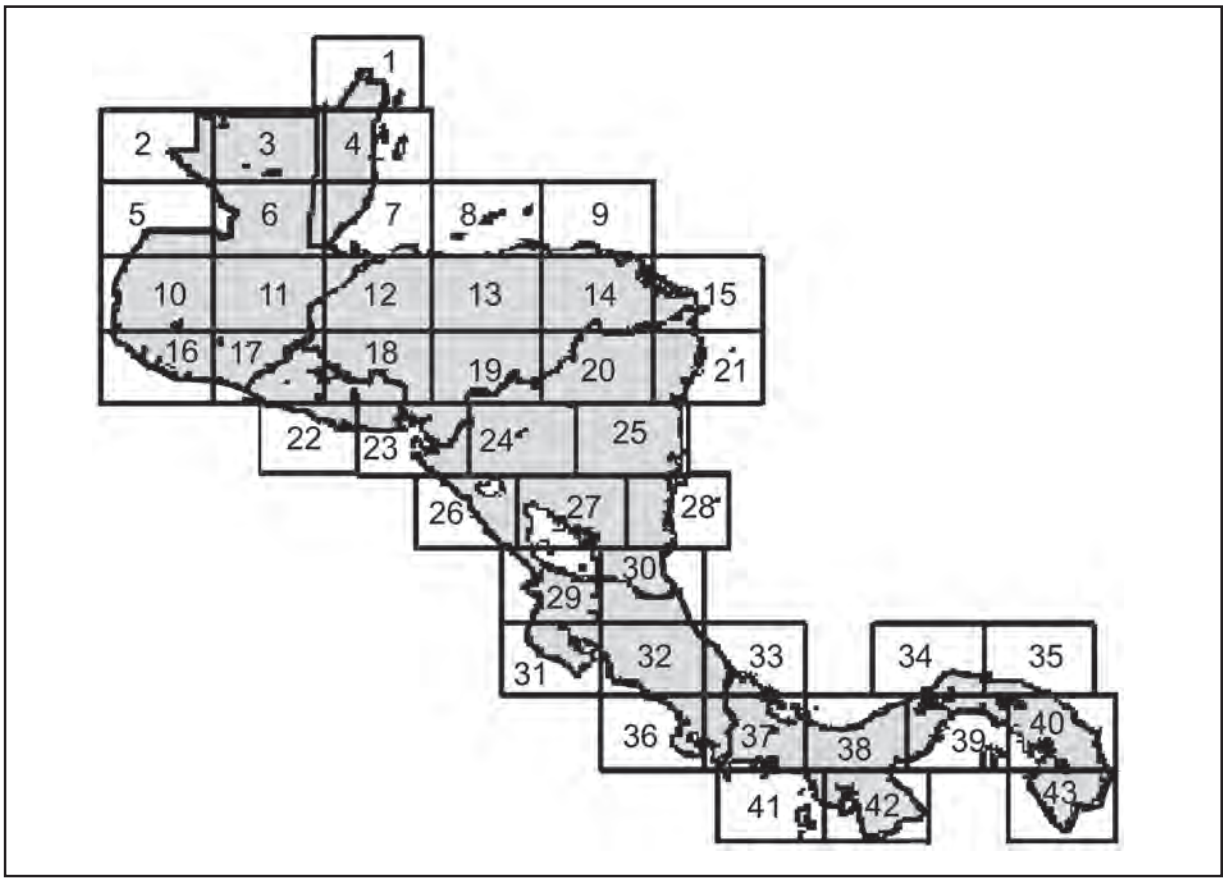
The overall objective of the Central American Ecosystem mapping project was the creation of a regional map at a scale of 1:250,000. Presentation of the full set of maps on paper requires that the overall map be divided into a set of individual maps.

The initial grid for creating the individual maps was defined arbitrarily on the basis of the size of the final output. The borders of the individual maps were then adjusted to avoid including empty maps with tiny slivers of map data in a blank frame. The initial 1:250,000 grid included 56 map sheets, but with the careful adjustment of boundaries and elimination of superfluous coverages, the map set was reduced to 43 maps as illustrated in Figure 2.

The completed map was then sectioned into rectangles corresponding to the 43 map sheets, inserted in the documentation frame of the 1:250,000 set, and saved to Windows Metafile format files. This permits electronic distribution of the full map set and avoids the cost of reproducing full sets in cases where the user only wants coverage of a particular country. The entire regional map file and the 43 separate map sheets are available through the World Bank web site (they are actually stored on the servers of EROS, courtesy of the USGS).

It should be noted however that the individual map sheets may not always be appropriate for exacting work in individual countries. Since they are based on a regional projection (as described above), they are by definition in a different projection from any map used nationally. This means, for example, that it would be impossible to precisely overlay national topographic maps. To do so, it would be preferable to reproject parts of the regional map using national projections.

Figure 2. Grid of Individual Maps



3. Results

The main results of the mapping project consist of:

- Regional consensus on an ecosystem classification methodology.
- Processed and georeferenced satellite images used in the course of the project.
- GIS vector files of the ecosystem maps of each of the seven countries, as well as a regional map, with coordinated classification nomenclature.
- Ecosystem descriptions with good biological background information.
- MS Access–based database with the field data collected in the context of the project.
- Expansion of national herbariums with several thousand herbarium specimens.
- Training of leading scientists from the ecological sciences community of each participating country.
- Final report in Spanish and English and a final integrated map.

A total of 197 ecosystem classes have been recognized in the context of this study (including agriculture and urban). About 25 additional codes have been defined using modifiers for levels of human intervention, but these do not represent distinct ecosystem classes per se.

3.1 Results by Country

Each country was mapped by a seperate team, using slightly different approaches, national standards, and preferences. The following subsections review some distinctive results for each country and differences between countries. Note that where we refer to the national reports, these can be found, perhaps in an abridged format, on the World Bank or WICE web sites.

Belize

A comprehensive and detailed national report for Belize was prepared by the Belizean team (Meerman and Sabido 1991).

Earlier mapping

Two national vegetation maps already existed for Belize: Wright et al. (1959), and Iremonger and Brokaw (1995). The "Natural Vegetation Map" by Wright et al. was a very detailed effort to map all natural vegetation classes on a scale of 1:250,000. The mapping was done on the basis of aerial photographs and extensive ground observation; the map dealt with natural vegetation but did not cover productive systems (areas with less than 50 percent natural vegetation cover). The classification was mostly physiognomic but contained some floristic elements.

The Iremonger and Brokaw vegetation map and classification system was based largely on the Wright map. However, their map recognized deforested areas with spontaneous regeneration of vegetation, and they also introduced a liberal form of the UNESCO-based classification. Iremonger and Brokaw each spent six weeks traveling the country by land, and additional field verifications were carried out by other biologists. There is no quantitative information on the field work carried out by Wright.

Both of these products formed the basis for the current mapping project, and the team primarily focused on reviewing and updating the Iremonger and Brokaw work. Their classification was made compatible with the Central American project, and known errors were corrected.

Level of effort by current team

Due to the small size of this country (22,963 square kilometers), it was possible to map it in considerable detail. Although the minimum polygon size for the overall project was initially set at about 150 hectares, for Belize the minimum size used was approximately 10 hectares and in a few cases even smaller polygons were created.

The main reference for the above-mentioned corrections were two Landsat TM images covering the northwestern and southernmost sections of Belize:

- Landsat TM Path 19, Row 49, 17 May 1996, in Erdas v7.4 format
- Landsat TM Path 19, Row 48 (partial), 15 September 1998, in Erdas v7.4 format.

Initial work and work on areas not covered by the above scenes was done on the basis of a 1993 hardcopy Landsat TM composite at a scale of 1:250,000 with detailed follow-up field verification. This copy was prepared by the Dutch consultancy group DHV, and is composed of spectral bands 4, 5, 3.

In the context of this project, 38 additional field visits were made, particularly to further clarify complex Belizean lowland savannas. In addition, valuable data were obtained from a multitude of reports. The project also benefited from data obtained from a considerable number of overflights conducted by the various team members.

The senior investigator in Belize (Meerman), identified the species he was familiar with in the field and collected unknown species for laboratory identification for the Herbarium of the Belize Forest Department. Particular emphasis was given to savanna ecosystems and some other classes that had received less attention during the previous mapping exercises. Given its long mapping history, the Belize map is among the most detailed maps in the region.

Ecosystem highlights

Ecosystem highlights were the lowland savannas, which proved very complex and difficult to map satisfactorily (particularly the two short-grass savanna classes with varying cover of needle-leaved dense forests).These are vast open grasslands, usually with compacted, moderately acid soils, which are alternated with mosaics of scrubs, isolated trees, poorly developed forests, and gallery forests. Fire plays a very prominent role. Unlike the other countries of Central America, Belize lacks major elevations. In most of the country the vegetation shows a pronounced seasonality, even in the evergreen forested areas. This is due to a dry season that lasts from February through May.

Guatemala

The Instituto Nacional de Bosques (INAB) has distributed on a CD the national ecosystems map as well as a detailed, high-quality national report (INAB 2001).

Level of effort by current team

Given the large size of the country (108,889 square kilometers), the mapping was done in somewhat less detail than in some other countries. Data collection in Guatemala has been very reliable with regard to species sampling, since all data were taken by the senior investigators themselves, either in the field or using their laboratory facilities. However the physical ecosystem descriptions were rather scanty and collection of physical data from the field needs to be strengthened in the future.

Ecosystem highlights

The largest remaining set of natural ecosystems in Guatemala is found in Petén, the country's northernmost department. The Petén is an interesting ecosystem complex consisting of very poorly drained, lowland swamp forest with extended herbaceous swamps, alternating with regions of karstic hills. Another interesting area, although much intervened, is the Motagua Valley which lies in a well-defined rain shadow, and thus displays semidesert characteristics. The resulting thorn scrub ecosystem has many distinctive characteristics and endemic species, and is found nowhere else except on a smaller scale in northern Honduras.

Table 8. Image Data Set Used for Guatemala

Path	*Row*	*Date*
21	48	01-19-99
21	49	01-19-99
21	50	01-19-99
20	48	01-12-99 04-14-86*
20	49	01-12-99 12-24-97 04-14-86
20	50	01-12-99
19	48	12-04-98
19	49	02-19-98 03-17-96
19	50	02-19-98 03-17-96

* Older images were used to substitute for some areas because of cloud cover.

El Salvador

The national report was prepared by Ventura Centeno et al. (1990).

Earlier mapping

The first vegetation maps of El Salvador were prepared in the 1950s by Lötschert and Läuer, and were based on climatic zonation. Guierloff-Emdem expanded the climatic system with data obtained in the field. Holdridge (1975) used the ecological life zone system to develop a ecological map of El Salvador. Daugherty (1973) classified six main classes of forest, divided into forest formations of highlands and lowlands, but also included nonforest vegetation types such as beach vegetation and shrublands. Finally, Flores (1980) prepared a classification based on 13 vegetation communities and listed typical plant species for each of these.

El Salvador is the smallest country in Central America (21,040 square kilometers) and included only 19 natural ecosystems classes. Although 26 percent of the country is covered by fragments of natural (terrestrial and aquatic) vegetation, much of it is in classifications of human-intervened vegetation. We estimate that little more than 6 percent of the vegetation cover is natural forest. Because seminatural or even substantially altered habitats are becoming increasingly important for conservation, the Salvadoran team paid extra attention to anthropogenic habitats and classified two seminatural (intervened) ecosystems and seven agricultural systems.

Table 9. Image Data Set Used for El Salvador

Path	*Row*	*Date*
18	50	3-5-94 and 12-29-98
18	51	12-29-98
19	50	5-1-92 and 12-4-98
19	51	1-2-98

For preparation of the map the El Salvador team used eight georeferenced Landsat TM scenes: four from before Hurricane Mitch (May 1992 and March 1994) and four from after (December 1998).

A very detailed level of effort was required to map El Salvador's highly fragmented natural ecosystems, and the country's small size made it feasible. As a result, the El Salvador ecosystems map is more detailed than those of neighboring countries. The level of reliability of all taxonomic data gathered is considered high because they were identified by the senior investigators themselves in the field or collected as specimens for identification in their laboratory facilities.

Ecosystem highlights

Due to the detailed mapping, the national team discovered an interesting páramo-type vegetation with dwarf shrubs on high volcanic slopes. No páramo vegetation had previously been identified so far north. It is quite possible that similar vegetation can be found on some of the high peaks in Guatemala and Honduras, such as Celaque (House, pers. comm., 2001).

Honduras

Earlier mapping

The area of Honduras is 112,492 square kilometers. Holdridge produced a life zone map for the country with eight life zones. AFE-COHDEFOR produced a forestry map in 1995 with five forest classes. In 1997 Iremonger, Nelson, and Vreugdenhil produced a map on the basis of 1994/95 Landsat imagery printed in bands 4, 5, 3. The map was printed in working sheets at a scale 1:250,000, but not in multiple copies.

Plant collections for the first version of the map were made by Cirrilo Nelson. At that time it was not possible to take GPS readings for lack of affordable equipment, and a database was not yet available. Consequently, the collected species are interesting as data for the region, but they cannot be used for the present ecosystem descriptions because we do not know the precise sampling locations. The map was very detailed and included about 70 classes. It used an adapted version of the UNESCO classification system. However, it needed to be updated using different elevation lines, and some of the classes needed to be reclassified under productive systems for the Central America Ecosystems Map.

Level of effort by current team

The current map has about 65 classes. For verification of the Iremonger map, the national team decided to use random relevé selection as the basis for data collection under the current project. This resulted in the collection of numerous relevés located in agricultural production systems. These data, as well as other ecological considerations (see next paragraph), suggested that in Honduras several of the pine classes recognized by Iremonger should be considered productive systems rather than natural ecosystem classes.

Honduras proved to be a very difficult country to map. The country has many dry regions with sporadic woody vegetation, dominated by *Pinus* species. The sizes of the trees vary from shrub-size to full-size trees. Their density varies from closed forests to almost treeless savannas, with most of the areas being intermediate.

Ecosystem highlights

Honduras and northern Nicaragua are reached by the southernmost ranges of a mountainous system that extends from North America. Many northern and even some boreal elements thus find their southern distribution limits on the peaks of the high mountains of Honduras or Nicaragua. Several coniferous species, like *Pinus oocarpa*, *P. hartwegii, P. ayacahuite,* and *P. maximinoii*; *Abies Guatemalensis; Cupressus lusitanica;* and *Taxus globosa* are found at higher elevations in Honduras but only *Pinus caribea* extends further south into the lowlands of Nicaragua.

Large areas of Honduras are covered with forest types dominated by *Pinus caribaea*, which may vary from savanna formations to poorly developed forest. All of these forests are subject to pressure from human activities. All of them are periodically burned, and in central and west-

Table 10. Image Data Set Used for Honduras

Path	*Row*	*Date*
15	50	9-1-1999
16	49	11-16-1995
17	49	2-23-1993
17	50	2-23-1993
17	51	2-23-1993
18	49	3-5-1994
18	50	3-5-1994
18	51	12-29-1998
19	50	12-4-1998

ern Honduras they are grazed as well. About 200 relevés were taken in areas classified in the Iremonger map as "very sparse pine forest" ("*bosque de pino muy ralo*"). In the world of production forestry, those areas were considered to be forests or forestry systems, but with more that 200 relevés in these sparsely treed areas (consisting of a mix of sparse forest, woodland, and savanna classes), it became clear that in the context of the current study these classes had to be revised, and thus many of those areas have been placed under "productive systems." In a land-use map many of those areas would be classified as forested grazing systems ("*sistemas silvopastoriles*").

In the Mosquitia (both Honduras and Nicaragua), the Caribbean pine forests and savannas are frequently burned and resemble the pine forests of the Belizean coastal plains. These areas are very difficult to map from satellite images, as their physiognomic conditions vary greatly over relatively small distances. Their physiognomic diversity is not, however, a reflection of ecological variability but rather the result of continuous disruptions from fire and grazing. These tend to be separated into different classes under the UNESCO system, but this does not necessarily reflect differentiation in sets of species. This is very similar to situations observed for the savannas of Africa, which are subject to similar conditions and where the rapid structural changes following fires correspond little with floristic diversity (McDonald et al. 1996).

The Honduran Emerald *(Amazilia luciae)* is an extremely restricted, country-endemic species of hummingbird. It resides in the dry deciduous thorn forest of the Aguán Valley, which lies in the rain shadow of the Cordillera de Nombre de Dios, but the species may also be found in isolated valleys in other parts of northern Honduras (Howell and Webb 1995). The particular class is considered a scarce and important ecosystem and is possibly related to the ecosystem of Motagua in Guatemala.

Nicaragua

Nicaragua, size 128,410 square kilometers, was first mapped as a country by Taylor (1962), who used his own version of a physiognomic classification for about a dozen different forest classes. Each class was described with considerable detail in an accompanying document. In the 1970s Holdridge and Tosi described the life zones in a map format, and in 1993 Salas proposed a forest map based on a system similar to that of Taylor.

Level of effort by current team

The methodology used in Nicaragua was somewhat different from any of the other countries (Meyrat 2000). The national team put a lot of emphasis on training and participatory production of the map. It organized broad national training courses in mapping methodology to which it invited external aquatic biologists and botanists from Costa Rica. It also recruited three teams of recent graduates to carry out the fieldwork.

This approach had both advantages and disadvantages. The methodology was embraced at an even broader scale than in the other countries of Central America. Some 15 young biologists were trained in both fieldwork and mapping work during a period of almost a year. On the other hand, the lead ecologist (Meyrat) was much involved in organizational work and seldom went into the field, so much of the field data have come from relatively inexperienced biologists. Therefore, sometimes the relevés may not have been the most representative of the polygon and there may be some species identification errors in field data. Collected specimens were identified by the lead ecologist, and those data are reliable.

Ecosystem highlights

Nicaragua is truly tropical, with a distinct difference between the dryer Pacific coast and the wet tropical Atlantic coast in the south. Cold spells, common in Guatemala and Belize and occasional in the higher regions of Honduras, are virtually unknown in Nicaragua.

On the Pacific plain two relatively large tectonic lakes can be found. Lake Managua (Lago Xolotlán) is in an advanced eutrophication condition. On the other hand, Lake Nicaragua (Lago Cocibolca) has a stable dynamic. In both lakes there are endemic fish species.

Although in Guatemala, El Salvador, and Costa Rica we can find vegetated lava areas and crateric lakes, they do not occur in ecological conditions (climatic and floristic) similar to those of Nicaragua. The lava flows in Nicaragua occur in the lowlands, creating higher hydric stress for the vegetation than is the case in other areas in Central America, where lava flows appear in highland areas. The crateric lakes of Nicaragua are unique

Table 11. Image Data Set Used for Nicaragua

Path	*Row*	*Date*
14	54	28 Jan. 1986
15	50	28 Apr. 1998
15	51	19 Jan. 1997
15	52	19 Jan. 1997
15	53	6 Feb. 1986
16	50	12 Mar. 1996
16	52	25 Jan. 1986
17	50	23 Feb. 1993
17	51	19 Dec. 1997
17	52	8 Feb. 1999
18	51	29 Dec. 1998

for their endemic icthyiofauna of cichlids and their relatively undisturbed state.

An interesting phenomenon that is particularly notable in Nicaragua is the formation of cloud "coronas," or crowns, around the volcanoes of the southern Pacific coast (the "telescope effect" or *massenerhebung*). Located in a relatively dry region, these volcanoes have remarkably more moist forests than the surrounding area even though the true precipitation may not be much higher. Crowns of clouds often persist during a good part of the day, providing vegetation with moisture and protection from direct sunlight.

Though found in other countries, Nicaragua contains the southernmost occurrence (about 12°30′ north latitude, UTM 14) of both the seasonally evergreen submontane pine forests (characterized by *Pinus oocarpa*) and of the inundated pine savannas (dominated by *Pinus caribaea*).

On the Caribbean plains we find seasonally evergreen forest dominated by bamboo, which is unique in Central America. This may represent a succession stage following a disturbance to the riverine forest by natural disaster or human intervention.

There are two kinds of mangrove ecosystems. One is composed of mangroves on a loamy substrate along the border of coastal lagoons. In these formations one finds "mangle piñuela" *Pelliciera rizophorae* (Theaceae), which in Central America is only found on the Caribbean coast of Nicaragua and Panama and the Pacific coast of Costa Rica. This indicates that the species spread from one side to the other before the formation of the Mesoamerican land bridge. The other Nicaraguan mangrove formation appears over a coralline substrate in the Miskito Keys.

The expanse of submarine seagrass prairies (beds) surrounding the myriad keys and reefs off the Caribbean coast of Nicaragua may be the largest of its kind in the world. It is dominated by turtle grass (*Thalassia testudinum*) and manatee grass (*Syringodium filiforme*) with high primary productivity. However, these areas were not mapped in the current project because of difficulty delineating them.

Costa Rica

Earlier mapping

A detailed ecosystem analysis for Costa Rica, though no map, was performed by Holdridge et al. in 1970, providing ample detail on tropical forest ecosystems. The life zones map for Costa Rica, made separately by Holdridge et al. (1970), shows 12 life zones. Gómez (1986a), using aerial photos, produced the previously mentioned "*Macro-tipos de vegetación de Costa Rica*" following the UNESCO classification system, and based in part on the *Mapa de las Regiones Climáticas de Costa Rica* (Herrera 1986) and the *Mapa de Suelos de Costa Rica* (Tournon and Alvarado 1989). The map legend also provides detailed soil classes associated with the vegetation classes. An accompanying report, "Vegetation Map of Costa Rica," provides thorough documentation. This work formed the underlying starting point for the current map file.

It should be noted that Costa Rican ecosystems are currently being mapped at much greater detail (1:50,000) by INBio as part of their ECOMAPAS Project. They are using a classification system similar to the Central American ecosystem classification used here. About half of Costa Rica had been mapped by the beginning of 2002.

Level of effort by current team

The country was divided into seven sectors that contain substantially different sets of species. This division was based on biogeographical analysis carried out in the context of the map projects of Gómez (1986a) and Herrera and Gómez (1993). The seven sectors are:

- Pacific north and central valley (including the eastern central valley)
- Mountains of the Guanacaste, Central, and Talamanca ranges
- The General and Terraba valleys
- Pacific south
- Northern watersheds (including all watersheds that run into the Río San Juan, from the Río Sapoa to the Sarapiquí watershed)
- Northern Atlantic watersheds
- Southern Atlantic watersheds

The project was severely hampered by poor and inconsistent georeferencing of the printed images and small but significant deviations from the 1:200,000 printing size of the images. This caused significant problems in the transfer of elevation lines from the topographic maps. At the request of the lead biologist,

Table 12. Image Data Set Used for Costa Rica

Path	*Row*	*Date*
14	53	01-18-99
14	54	02-16-98
15	53	03-99 09-98 02-06-86
15	54	04-03-92
16	52N	12-15-98
16	53S	01-10-97

most images were processed in band combination 5, 4, 3. In the context of the digitization, all images were georeferenced again and processed in bands 4, 5, 3. In this process some of the previously experienced problems were addressed. Specific sites were selected to obtain complementary data and verification of the previous mapping efforts. The fieldwork was done by a team of biologists and field samples were reviewed in the laboratory and verified by the lead scientist. The data are considered reliable.

Ecosystem highlights

Costa Rica is the only country that has protected a large area of the dry Pacific region spanning semi-deciduous, deciduous, and savanna conditions. Even though this area, in Guanacaste Province, has been under extensive livestock management for decades, it probably has retained many of its original species. Together with Panama, Costa Rica contains the only páramo in the region similar to the Andean páramo.

Although species diversity in Mesoamerica is generally considered to increase from north to south, this is not reflected in the number of ecosystem classes found in Costa Rica and Panama. This is due to the fact that the UNESCO system distinguishes between broad-leaved, mixed, and pine formations. Mixed and pine formations are absent south of the Nicaraguan depression. As a result the maps of Costa Rica and Panama show lower numbers of ecosystem classes.

Panama

Earlier mapping, differences in mapping

Panama does not have a previous ecosystems or vegetation map other than the very basic life zones map from 1974 with eight life zones. A detailed, supervised classification was carried out for Bocas del Torro by Guzmán and Guevara (1998) with detailed mapping of mangroves, seagrass beds, and some coral reef classes.

Level of effort by current team

With 77,081 square kilometers, Panama is a medium-size country in the region. The Panamanian team adhered very closely to the original agreement of a minimum polygon size of about 150 hectares. As a result, some of the smaller-size ecosystems that were individually recognized have been clustered or ignored on the map, but they have been mentioned in the final national report. This was particularly the case with the littoral ecosystems of Bocas del Toro. A supervised classification for the coastal zone of Bocas del Toro by Guzmán has not been incorporated in the GIS file.

Most of the field work in Panama was not executed by the senior botanists in the country, but rather was done by biologists with 5 to 10 years of field experience. Species collected in the field that were not recognized were identified later in laboratory facilities and with the aid of the electronic web page of the Missouri Botanical Garden. The quality of both physical and taxonomic data is considered to be good.

Ecosystem highlights

Fewer classes have been identified in Panama than in some of the other countries. This is particularly due to the moister conditions of the country as a whole. Forest is the natural vegetation almost everywhere except in a narrow region at the coast of Azuero. Natural, open bodies of freshwater are virtually nonexistent in this narrow mountainous country. The only sizeable swamp formations are in the far east and far west. The distinction between Pacific and Caribbean mangroves has not been made. Initially the mangrove class with *Pelliciera rhizophorae*, which is considered to be in a category of its own, was not recognized by the national team, but it was identified later from literature for Bocas del Toro (Guzmán 1998).

Specific highlights in the regional context are a peat swamp on the northeast coast, the previously mentioned páramo, and extensive coral reefs off the Atlantic coast. Coral reefs, though not mapped in the current project, are an important ecosystem. Substantial information on the reefs has been collected by Guzmán and Guevara (1993) and Guzmán (1998) and is being analyzed in the context of another project (Guzmán, pers. comm., 2001).

Table 13. Image Data Set Used for Panama

Path	*Row*	*Date*
10	54	03 - 21 - 91
10	55	03 - 21 - 91 07 - 08 - 96
11	54	02 - 27 - 98
11	55	03 - 31 - 98
12	53	04 - 07 - 98
12	54	04 - 07 - 98
12	55	03 - 09 - 99
13	54	03 - 26 - 97
13	55	03 - 29 - 98
14	53	01 - 18 - 99
14	54	02 - 16 - 98 04 - 02 - 97

4. Discussion

4.1 Important Ecological Factors

Many users of the maps, database, and ecosystem descriptions will be looking for patterns. Why is this ecosystem found here? Where else could it occur? What determines its distribution over Central America? For a better understanding of the individual ecosystems, it is important to understand some of the ecological factors that underlie these ecosystems. Some of the most important ecological factors include drainage, elevation, climate, and fire. Much more research is required to understand their relative importance, but we provide here some of our thoughts on these ecological factors.

Drainage

Drainage is a very important factor in the local determination of ecosystems. Whether plant species are tolerant to waterlogging determines where they can grow and thereby determines the ecosystems that develop. Slope is a predominant factor for drainage. For this reason, in the ecosystem classification followed here, all hilly and mountainous areas have been classified as "well drained." On the scale of this map, such well-drained areas may well have a mosaic of pockets of moderately drained and/or inundated terrain, but the predominant conditions in the ecosystem at large will be well drained.

For soil organisms and plants, poor drainage and flooded conditions are extremely demanding conditions, requiring either sophisticated mechanisms for gas exchange, escape from saturated or flooded conditions, or some form of seasonal dormancy.

Aquatic species, on the other hand, may greatly benefit from such conditions. Flood plains inundated during the wet season can make the habitats of riverine organisms such as fish and crocodiles tens or even hundreds of times larger than during the dry season when the river is at minimum flow.

Migratory birds may travel thousands of kilometers to find such wetland conditions. Amphibians are particularly partial to seasonal ponds that are not connected to other water systems, and where as a consequence they are not preyed on by fishes. Such conditions abound in moderately drained to gently sloping areas with small isolated pockets of water.

Flooding and waterlogging creates rather extreme conditions, and relatively few species have evolved to deal with this situation. As a result, species diversity in poorly drained conditions is typically lower than under well-drained locations nearby. On the other hand, the amount of biomass is often much higher, and wetlands are often good places to see large quantities of wildlife, especially birds. Permanent inundation may lead to accumulation of peat. In the tropics this is a relatively rare phenomenon. In the study areas this is mainly found on the border between Costa Rica and Panama.

Central America is split into two main drainage systems: the Pacific and the Atlantic. The Atlantic is the larger of the two. For aquatic fauna and flora of limited mobility this division is very important because connectivity is through the rivers and streams. Aquatic animals on the two sides of the continental divide are completely separated from one another. Plant species however appear to be the same.

Often the presence or absence of flow (Gómez 1984) is used to divide aquatic habitats. Flow is very important ecologically. Currents are a factor of physical dynamics in an ecosystem. They transport nutrients and sediments and affect biological connectivity. In most aquatic ecosystems some flow is present, but this study has not systematically incorporated the presence or absence of flow except by recognizing rivers and estuaries as typically lotic systems.

Most rivers and all minor streams were too narrow for mapping and thus all terrestrial ecosystems can be considered to include, to variable degrees, a fine maze of aquatic ecosystems with parallel narrow flood plains.

Elevation

Differences in elevation result in climatic differences. As mentioned previously, five elevation levels have been used as a proxy for climatic differentiation. Elevation may also be a factor in population isolation. When highland areas have a disjunct distribution, genetic isolation of the adapted flora and fauna may result, and highland regions are believed to have larger numbers of endemic species.

In this respect it important to recognize the region's two distinct mountainous blocks. One is in the northern half, extending from Mexico, through Guatemala and Honduras, and into Nicaragua. The highest peaks in this block are in Guatemala and reach 4,211 meters (Volcán Tajamulco). The second distinct block is in the south, running from Costa Rica into western Panama. The highest peak in this block is Cerro Chirripó, in Costa Rica, which is 3,819 meters high.

Species composition differs between mountain regions for various reasons. The north-south temperature increase, together with an effective isolation of higher elevation species by the Nicaraguan Depression, had an important effect on inhibiting species invasions between northern and southern Central America. In particular, temperate boreal species could not migrate further south (for example pine species, whose southern limit is in Nicaragua).

On isolated mountains the vegetation response to elevation-related conditions appears to occur at lower elevations than on large mountain ranges such as the Talamanca. This phenomenon has been referred to as "massenerhebung," or the "telescope effect" (Hammen and Ruíz 1984), and has been observed on several isolated volcanoes in the region. An example is the Maya Mountains in Belize. They do not reach much higher than 1,000 meters, but still contain plant species that do not occur below 1,000 meters in nearby Guatemala and Honduras (such as *Liquidambar stiraciflua*, which in Belize is found at elevations as low as 700 meters). Similarly, in Honduras and Nicaragua scrub formations grow on isolated mountain peaks at elevations where one would still expect to find forest. In El Salvador a páramo-like vegetation is found just above 2,000 meters. Grubb suggested that the frequent presence of clouds causes the phenomenon. In particular, the isolated volcanoes from El Salvador to northern Costa Rica are frequently covered with "crowns" of clouds that may even occur during the dry season when the sky is otherwise clear.

Fire

Most of Central America is constantly effected by fire. Although the role of fire in ecosystem formation and continuity is not well understood, it has long been recognized as an important factor. For example, in 1937 Lundell described fire as an important phenomenon in the Petén.

Since pines (*Pinus* species) are generally more fire resistant than broadleaf trees, fires prevent broad-leaved forest species from invading and replacing pines on soils that might otherwise carry broadleaf forest. Landscapes dominated by pines (such as in central and western Honduras) are therefore generally considered to be fire induced (Knapp 1965).

Most fires are set by people. However, data for the Mountain Pine Ridge Forest Reserve in Belize for 1963–70 indicate that out of 46 recorded fires, 29 (63 percent) were caused by lightning strikes and 17 (37 percent) by people. In contrast, on the southern coastal plain of Belize the great majority of fires were set by hunters trying to flush out game (ODA 1989; Meerman personal observations).

Fire is a key feature of the coastal savannas of Belize and the Mosquitia. We believe from observations during this study that savanna development results from a combination of factors:

- Compacted, poorly drained, acidic soils that are often inundated during the rainy season and extremely dry during the dry season.
- Somewhat longer dry seasons compared to the Atlantic coast elsewhere in the region.
- Frequent fires, mostly but not exclusively of anthropogenic origin.

In the Mosquitia, AFE-COHDEFOR has protected a few plots of what originally was pine savanna from fire for more than 15 years. These plots have grown into regular pine forest with a conspicuous understory of broad-leaved shrubs. Apparently, without fire large parts of these savannas would turn into forest. The combination of infrequent lightning strikes and the seasonal desiccation of Caribbean pine forest communities indicates that to some degree fire probably forms a natural part of these ecosystems. That said, under natural conditions the savannas would not be burned as often and they would not be as widespread as they are with the current human influence.

Fires in broadleaf forests are often ignored and at times seem to bear no resemblance to the massive blazes that can be seen in needle-leaved forests. Fire in broadleaf forests is usually low, creeping slowly through the leaf litter. Nevertheless, these low, slow-moving fires can be profoundly destructive. Trees, especially young trees, may appear unharmed at first, but many will die over time as a result of direct damage or indirect damage such as increased pathogen access through the fire-damaged bark. Tree mortality as the result of such slow fires may continue for several years after the actual fire (Meerman, pers. obs.). Each fire that leaves more dead or dying trees behind makes the forest even more susceptible to new fire damage.

In a few forests, such as hilly forests and those with Cohune palms (*Attalea cohune*), the effects of fire can be more dramatic. The abundant leaf litter under Cohune palms explodes into flames, often igniting the crown and spraying sparks over great distances. Fires are most devastating on hills where an upward draft creates extremely hot fires (and the greatest damage) toward the top of the hill. Repeated fires result in "bald" hills with a cover of grasses and/or ferns (notably *Dicranopteris* and *Pteridium caudatum*) rather than woody vegetation. The influence of fire is clearly greatest where there is drought stress (such as on the tops of karstic hills) and in the presence of highly inflammable vegetation. On karstic hills the effects are particularly devastating since the soil layer is

thin and highly organic in nature, and therefore easily destroyed by fire.

Slash-and-burn agriculture is the main culprit for fires in lowland broadleaf forests. Subsistence farmers generally do not take escaped fires seriously. Burned hill tops are virtually always connected with agricultural clearings at the foot of the hill.

Until recently, the frequency, magnitude, and effects of wildfires on ecosystems and biodiversity in Central America were virtually unknown. The recent publication of the *Atlas Centroamericano de Incendios* (Proyecto de Frontera Agrícola 1998) documented the wildfires during the 1998 dry season using satellite image data. The study suggested that most fires take place in areas under agriculture and in areas bordering remaining natural vegetation, including in protected areas.

Not all savannas and open herbaceous ecosystems in Central America originated by fire. In particular, some savannas in the Guanacaste region are drought savannas that would not develop into forests even without fire because of climatic conditions and soil characteristics. The saline flats of the Golfo de Fonseca in Honduras and Nicaragua, and of the Azuero region of Panama, are open herbaceous vegetation types that also are not fire related.

4.2 Biogeographical Considerations

Biogeography is the study of the geographic distribution of plants and animals. It is concerned not only with patterns but also with the factors responsible for those patterns.

A factor of major importance in the Central American context is that the area forms a link between North and South America. Not surprisingly, there is a north/south cline for species of North American origin and a south/north cline for tropical species originating in South America.

Gómez (1986a) recognizes several biological regions along the isthmus on the basis of sets of species and genera:

1) Caribbean Region. Includes all the Caribbean islands, parts of Florida and the Yucatán peninsula, the Caribbean regions of the Central American isthmus, and the Caribbean coasts of South America. In Central America the Caribbean biological region is characteristic of the coastal regions of Belize and Honduras.
2) Boreal Xerophytic Region. Populated by nearctic elements distributed in arid or subarid areas. Characteristic plant families are Agavaceae and Cactaceae. The region includes much of the Yucatán peninsula, Mosquitia, and most of the Pacific coast.
3) Neotropical Region. Includes the majority of the Caribbean Central American lowlands as well as the humid highlands. It is characterized by species with affinities to the humid tropics of South America. Highlands with affinities to the high mountainous regions of northern South America are recognized as a distinct province within the Neotropical region: the North Andean Province. These highland areas in Central America occur in two distinct blocks separated by the tropical lowlands of Nicaragua. As a result they are frequently recognized as two subcenters: Guatemaltecan and Talamancan.

It should be recognized that we are dealing with regions that have great numbers of species, each with their own distribution patterns. In biogeography, one generalizes and considers very broad tendencies.The regions described by Gómez seek to geographically group certain sets of species and genera, and not to split the region into distinct and mutually exclusive geographical zones. As a result these areas overlap, and therefore they could not be used in the current mapping project.

A somewhat different classification system is the concept of "ecoregion." An ecoregion is defined as a geographically distinct assemblage of natural communities that share a large majority of their species, ecological dynamics, and similar conditions, and whose ecological interactions are critical for their long-term persistence (Dinerstein et al. 1995). The ecoregion concept makes assumptions about the pre-Colonial distributions of species sets and ecological processes.

Dinerstein et al. recognize 18 ecoregions plus 13 mangrove units for Central America. These ecoregions show considerable affinities with the formation subclasses used in the UNESCO system. However, in addition to the differences in scale there also are differences in interpretation, which accounts for some of the discrepancies between the two systems. For example, Dinerstein et al. do not recognize savannas for Central America, but rather incorporate them into coniferous forests or dry broadleaf forests. At the other extreme is their recognition of so many mangrove systems. Given the high marine connectivity and relatively low species diversity of mangrove systems in general, perhaps there is insufficient basis for such a detailed classification.

A quick analysis of the ecosystems map reveals that, to some extent, distinct sets of ecosystems constitute biogeographic regions or ecoregions. Further study will be necessary to determine to what degree this is true.

A second major area that requires research and investigation is the possibility of using biogeographical classifications to fine-tune the ecosystem classification itself. For example, a tropical evergreen broadleaf low-

land forest that is moderately drained on the Atlantic side of Belize is likely to have a completely different species composition than a forest of the same classification on the Pacific side in Panama. Further study will be needed to determine if such regionalizations can be used to improve the ecosystems map.

We suggest the following as important issues to take up in the ongoing discussion on incorporating bioregional considerations into the classification system:

- *Distinction between the Pacific and Atlantic slopes*. The distinction between the Pacific and Atlantic slopes has already been mentioned in the definition of elevation zones. Even at elevations of 3,100 meters, in areas that are not very distant from one another, Kappelle (1992) finds significant "floristic dissimilarities" between Pacific and Atlantic vegetation classes. This is just one of many indications to justify a distinction between physiognomically similar UNESCO classes for the Pacific and the Caribbean. It is worth considering whether to make this a generic distinction at all elevations.
- *Montane biogeographical differences*. Several inventories carried out in the Sierra Madre region and in the central mountain massif spanning Costa Rica and Panama reveal interesting differences. Kappelle et al. (1994) describe a great phytogeographical affinity between the Talamanca region and the montane forests of the northern Andes based on detailed inventories. A comparison by Islebe and Kappelle (1994) shows that the "Guatemalan subalpine flora consists mainly of wide temperate, holarctic and neotropical herb genera, whereas the Costa Rican subalpine flora is principally made up of neotropical shrub and wide tropical tree genera, next to a small amount of wide temperate herb genera." This information, combined with the distribution limits of *Pinus* north of the Nicaraguan Depression, is ample evidence that distinctions should be made between the apparently similar UNESCO classes in the mountain ranges on either side of the Nicaraguan depression (Kappelle et al. 1992). House (pers. comm., 2000) tentatively reasons that the ecosystems of the Nombre de Dios range should be differentiated for being the most northern and most altitudinally isolated Atlantic mountain range in Honduras.
- *Aquatic ecosystems*. In the specific case of aquatic ecosystems, the Central American isthmus itself is a major biogeographical separator (or barrier) between the two oceans and between the freshwater ecosystems on either side of the continental divide. Therefore, the aquatic systems have been split into Atlantic and Pacific systems even though in some cases they were very similar botanically; further work is needed to determine if this is the correct approach.
- *Mangroves*. As mentioned previously, mangroves should not be divided up regionally because there is relatively low diversity of terrestrial species between systems. However, the characteristics of their constituent marine faunas perhaps justify a distinction between Caribbean and Atlantic ecosystems. If a distinct icthyiologic regionalization can be further defined between mangrove systems, they could be distinguished accordingly.

4.3 Biological Distinctiveness

At the beginning of this report we outlined a supposition that individual ecosystems represent distinctive assemblages of fauna and flora interacting within a framework of distinct ecological processes. An ecosystem classification for improving conservation planning and for a variety of research purposes is considerably more useful if this is true.

Note that physiognomic distinctiveness does not always lead to different species sets. Some dynamic ecosystems, such as the coastal Caribbean pine savannas of Belize and the Mosquitia, undergo frequent rejuvenation through burning. Because of continuous and varied environmental stress, mangroves also show great variation in their vegetation structure. Within such habitats, the structure may vary from locally dense forest to almost treeless savanna or scrub, but many of the same species occur within each of these different structures. When applying a presence/gap analysis one must be very careful with the use of data from areas with repeated environmental stress or human intervention because those areas may lack the species differentiation that is characteristic of other ecosystems with similarly distinctive physiognomic characteristics.

We found little literature on biological distinctiveness of ecosystems classified in physiognomic classification systems. The system developed by the Federal Geographic Data Committee/United States National Vegetation Committee (USNCS) is based on the UNESCO classification, with some slight modifications to meet U.S. needs, and the addition of a floristic characterization. At the time of publication, that system recognized more than 4,000 different habitats. A report by The Nature Conservancy on the USNCS system (Grossman et al. 1998) stated that "Ecological communities constitute unique sets of natural interactions among species, provide numerous important ecosystem functions and create part of the context for species evolution." It falls short

however, in arguing that ecologically different communities harbor distinctive sets of species. There is no scientific proof that the USNCS approach, which is based on a combination of physiognomic/ecological characterization with additional floristic subdivision, is indeed sufficiently biologically distinctive for a biodiversity conservation gap/presence analysis.

After careful review of our own ecosystem descriptions and the patterns of ecosystem distribution that the map shows for Central America, we provisionally feel that each ecosystem recognized in our classification represents a fairly distinct set of species. The classification reflects distinct physiognomic structures and climatic conditions, and these in turn are related to a series of important ecological factors that cumulatively result in distinctive species assemblages.

Each country in Central America has a relatively high number of classes within relatively small territories. Therefore, we feel that the expanded UNESCO system, as it has been used in the current mapping project, provides a level of detail that allows for responsible representation/gap analysis of conservation systems at a national level. This has proven to be true in an ongoing study in Honduras on the rationalization of the protected areas system (Archaga, pers. comm., 2002). However, much more research is needed to determine if some different level of precision in the classification is more appropriate for conservation planning.

4.4 Climate Change

There is a consensus in the scientific community that anthropogenic changes to the composition of atmospheric gases is having significant impacts on global climate. There is much uncertainty about the likely rate and magnitude of greenhouse-induced climate changes, especially at the regional level, but it is clear that there is potential for significant impacts on ecosystems throughout the world (Peters and Darling 1985; Hobbs and Hopkins 1991). Analyses of the climatic profiles presently occupied by plant and animal species, compared with future climatic conditions under various scenarios, suggest that the present areas of geographic distribution of many species will be climatically unsuitable within a relatively short time. If such predicted changes take place, survival of species will depend on their ability to adapt to new climatic conditions, or their capacity to shift their geographic distribution to track suitable climates. Those groups likely to be most affected include geographically localized and/or isolated taxa, peripheral or disjunct populations, specialized species, poor dispersers, genetically impoverished species (Peters and Darling 1985), and those in fragmented habitats embedded in human-modified landscapes.

It is generally accepted that temperatures in Central America will increase. Projections of the increase over the next 50 years range between 1.0 and 3.0°C (1.8 to 5.4°F). Estimates for average precipitation in northern Central America project decreases of between 4 and 19 percent over the next 50 years (Hulme and Sheard 1999). Southern Central America, however, may see a slight increase in precipitation.

Although all these predictions may be based on insufficient data, there is no doubt that major shifts in habitats will occur. One application of current ecosystem mapping projects will therefore be to establish a baseline for monitoring these changes. Although such monitoring does not address the actual problem, the results should provide powerful data for management of the region's natural resources.

It has been suggested that linkages between habitats, such as the Mesoamerican Biological Corridor, may play an important conservation role in adapting to climate change by (a) facilitating range expansion or shifts, (b) allowing for redistribution of species within their present range, and (c) creating larger, more genetically diverse, and more resilient populations of species (Harris and Scheck 1991; Hobbs 1992; Noss 1993).

First, in some situations linkages may allow plant and animal species to shift their geographic range in response to climatic conditions. However, great caution is warranted before concluding that linkages will actually fulfill this role. The rate of range expansion required to respond to the projected climate change is much greater than that known to have occurred historically or revealed by paleoecological analyses for most species, especially plants (Hobbs and Hopkins 1991; Noss 1993).

Range expansion may also be limited by ecological or anthropogenic factors despite the maintenance of seemingly suitable linkages. For example, climatic conditions may become more suitable in adjacent areas, but differing geological substrates and soil nutrient levels may be unsuitable for the plant species concerned.

Many species are dependent on complex ecological interrelationships with other plants and animals, and consequently an effective range shift would require migration of assemblages of coadapted plants and animals. The geographic location and necessary dimensions of linkages for such biotic migrations are not known, but it is likely that vast tracts of continuous natural habitat would be required.

Linkages across elevation gradients are the most likely to facilitate effective range shifts because the geographic displacement needed is much less than in areas with relatively uniform elevation such as the lowlands of Central America.

Second, linkages have a potentially important role in countering climate change by maintaining the continuity of species' populations throughout their *present geographic range,* thus maximizing a species' ability to persist within those parts of its range where climatic conditions remain suitable. Redistribution within an existing range is more feasible than range shifts to new areas.

Third, linkages also have a role in countering climate change by interconnecting existing reserves and protected areas to maximize the resilience of the present conservation network. Linkages that maintain large contiguous habitats or that maintain continuity of several reserves along an environmental gradient are likely to be the most valuable in this regard. Large populations and those that span environmentally diverse areas are likely to have greater demographic and genetic capacity to respond to changing conditions.

Despite present uncertainty about the specifics of climate change and its potential impacts, maintaining and restoring linkages between habitats is a prudent measure that provides conservation benefits regardless of the exact outcome of climate change.

5. Recommendations

In this section we summarize a few key recommendations for the next major revision of the Central America ecosystem classification, and a number of specific suggestions for research and investigation needs.

Worldwide Review of UNESCO System

After the initial introduction of the UNESCO System in 1974, several attempts have been made to improve it, but never in a concerted international context. It is recommended that we learn the lessons from a quarter century of use in many different areas of the world to thoroughly review the system and expand it to a classification system that can deal with all the ecosystems of the Earth, including aquatic ecosystems.

Further Definition of Aquatic Ecosystems

As was discussed in some detail earlier in this report, the UNESCO system imperfectly takes into account aquatic freshwater and marine ecosystems. In the context of this project we made some first steps toward the incorporation of such information into a comprehensive classification system. However, much work remains to be done.

Incorporation of coral formations seems particularly important, but could not be done adequately in the course of this project. Corals, being sessile animals, would seem to be suitable biological identifiers for ecosystems.

Gúzman and Guevara (1993, 1998) indicate that in quantitative terms differentiation of ecosystem types could only be recognized between seaward (exposed, dynamic) and leeward (protected, more tranquil) reefs. The practical classification of Mumbe (1999) was based on geomorphological conditions of the substrate in combination with its exposure to currents and waves. Guzmán has applied a supervised classification for Bocas del Toro that looks rather promising for the classification of at least a number of ecosystem classes.

However, we did not find a useful methodology (in the context of a satellite-based classification methodology) to distinguish between different coral reefs based on visible structural differences. Further work will be required to fully address this question.

It is worth noting that, at least for the purpose of analyzing the conservation priority of ecosystems, the coraline ecosystems of Central America may not need to be subdivided because they are of such great value that we can unilaterally declare them all to be a high priority for conservation.

Further Revision of the Central American UNESCO Classification System

In the main section of the report we mentioned a number of areas where our proposed Central American adaptation of the UNESCO system falls short or needs further work.

One example is the *pine forests in Honduras,* which were very difficult to classify (similar problems were noted in other countries but they were most acute in Honduras).

In the center of the country most of the pine areas are grazed and seasonally burned. A valid case can be made for classifying them as either intervened natural ecosystems or as production systems. The argument for the natural, intervened classification is largely that the vegetation, both grasses and trees, propagates spontaneously. However, the combined effects of grazing, intentional and large-scale burning, and occasional tree felling are usually so intensive and managed that these areas could very well be characterized as extensive agricultural production systems.

Both the limited biological distinctiveness and the severely affected natural state of the pine vegetation in large parts of the country should be taken into account when undertaking a representation/gap analysis.

Extension to Other Areas

Because of Mexico's geographical proximity and the fact that it forms part of the Mesoamerican Biological Corridor, it seems particularly urgent that ecosystem classifications for Central America and southern Mexico be conciliated and perhaps even defined under the same system. We urge that existing ecosystem maps of Mexico (all of Mexico has been mapped at a scale of 1:250,000) be evaluated to see whether they could be joined with those for Central America or at least made compatible.

We further recommend that the method be applied in South America, and that users be organized to collaborate on further development of the methodology.

Finally it is worth noting that although Costa Rica was entirely mapped at 1:250,000 in the course of this project, INBio and SINAC are spearheading an effort to completely map the ecosystems of Costa Rica at a scale of 1:50,000. About half the country has already been mapped in this

ambitious project. It is desirable to continue some level of coordination between the national effort and the regional effort to ensure interoperable classification systems.

It should be noted that the Central America ecosystem mapping project was primarily concerned with natural habitats. Areas that are classified with various degrees of human intervention are still, in our opinion, fundamentally functioning natural ecosystems. To further facilitate comprehensive land use planning in the region, it will be helpful to extend the mapping project to the entire isthmus, including all human-intervened areas.

Biogeographical Considerations

As noted in more detail in Section 4, much more work remains to be done in the area of incorporating regional distinctions (biogeographical or otherwise) into the classification system.

It would be particularly interesting to revisit the ecoregion approach as it has been applied in Central America to see if such a classification could help distinguish between ecosystem types in the region and to determine if the ecoregions themselves could be better defined using the data from this project.

Further Use of the Database

The Ecosystems Map of Central America and the Central America Monitoring Database have been designed to serve as the baseline for biodiversity and environmental monitoring in Central America. During the project the Central American Monitoring Database focused on the description of ecosystems and sessile species.

To improve its usefulness for a complete monitoring program, parameters need to be added that focus on processes causing species and habitat changes. In addition, elements need to be added for fauna and submerged aquatic elements.

We recommend that the CCAD and its member countries integrate both the map and database into a regionally coordinated monitoring system that allows for broad data exchange among the participating countries.

Icthyiological Aspects

As noted in the main text, we could not classify open-water systems because of the absence of vegetation. An alternative might be to rely on faunal elements, preferably macrofauna (plankton could perhaps be useful but have not been considered because of the difficult identification requirements). Fishes, some crustaceans, and mollusks are the most conspicuous taxa among the fully aquatic faunal elements. Of these, the ichthyiological fauna is the best known in the region, with national inventories for each country: Panama (Hildebrand 1938), Costa Rica (Bussing 1967), Nicaragua (Villa 1982), Honduras (Martin 1972), and Belize (Greenfield and Thomerson 1997). Myers (1966) considers primary freshwater fishes as among the best indicators for zoogeographic patterns because it is very difficult for them to cross sea barriers and major watershed divides.

Fishes can be considered as (a) primary freshwater fish, (b) secondary freshwater fish, (c) facultative freshwater fish and (d) peripheral freshwater fish, according to increasing salinity tolerance. Martin (1972) clearly shows distinct species distribution sets for lowland rivers and estuaries, midstream river systems up to 1,000 meters, and upper watershed systems mainly occurring above 1,000 meters. With the data available and the foundation of the analyses by Martin (1972), Villa (1982), and Greenfield and Thomerson (1997), we suggest that the fish data of Central America could provide a valuable basis for distinguishing between some aquatic ecosystems. This is an interesting area for further work.

As an important contribution to this effort, one of us (Vreugdenhil) has compiled comprehensive species lists of the freshwater fish faunas for each of the countries of the region, using the classification noted above. Such a list did not previously exist and will be a good starting point for a careful look at the usefulness of the fish data in defining open-water ecosystem classes. The list is posted on the WICE web site at http://birdlist.org/cam/central_america.htm.

Biological Distinctiveness

Further work is needed to determine if the ecosystem classes as defined in this project truly define distinctive ecological communities of flora and fauna that would be useful units in long-term conservation planning exercises. See the main text for a more detailed discussion and some specific suggestions.

Maintenance of the Ecosystem Working Group

The mapping project has brought together a group of highly qualified specialists who together represent a remarkable pool on knowledge on biodiversity and the ecosystems of Central America. We recommend that this group be maintained as a Vegetation Working Group that can continue to provide assistance on monitoring, data collection, and updating of the ecosystem map, etc.

Possibly this group could be brought together and maintained under the aegis of the CCAD or the MBC Regional Project. It needs to be expanded to include more emphasis on aquatic and faunal elements.

Maintenance of the Ecosystem Map

Perhaps the single most important recommendation we can make is that concerted efforts be made on the part of the Central American countries, the CCAD, and collaborating donor institutions to commit to the long-term maintenance of the Ecosystems Map of Central America.

The regional integrated map exists only as a snapshot resulting from the fusion of seven national ecosystem maps in late 2000. Since that time, each of the countries of Central America have continued to work on their national maps in accordance with their own priorities and interests. The maps will undoubtedly continue to be maintained and used in each of the countries.

However, a much greater effort is required to allow for continuing integration of the seven national maps. This is still very important for all the reasons laid out initially as objectives for this mapping project. Without this effort each country will not only be unilaterally modifying and remapping polygons in border areas, but the methodology itself will naturally evolve in different directions. In a number of years it would be either very difficult, very expensive, or perhaps impossible to produce another regional map.

We recommend strongly that every measure be taken to maintain the map on a regional basis, while of course respecting the rights and sovereignity of each country to define and maintain its own map (some countries may eventually have to agree to slightly different approaches in the presentation of their data depending on whether it is for national or regional purposes). Some of these measures include the following:

- Maintanance of the Vegetation Working Group.
- Nomination of an offical Focal point for the map in each country.
- Institutionalization of the regional map in a centralized process that will have to be both cost-effective and highly participatory.
- Continuing investment and effort in refining the methodology and ensuring the participation of all countries.
- Shared acquisition of new satellite imagery sets of the entire region.
- Definition of a process to allow data to flow from the countries to the central map as well as to allow data to flow easily to the countries (particularly in transborder areas).
- Support for the use of the map and the associated database in regional and national monitoring programs.

Presentation of the Map

The ArcView version of the regional map was produced by CATIE. The process is described in some detail in the main text. The entire ArcView file can be downloaded from the EROS web site (linked to the World Bank site at www.worldbank.org/ca-env).

This single file is critical for any analysis that requires looking at biodiversity or ecosystems in a regionwide perspective. It uses a projection that minimizes distortions in area between different parts of the map, but this of course introduces other distortions in the way the map appears, particularly in the northern and southern extremities.

The 43 map sheets that constitute the regional map can be downloaded from the EROS and World Bank web sites. However, the usefulness of a single map sheet in any given country is somewhat reduced because it is in a different projection than the country would customarily use. In some countries there will be other noticeable distortions in the map. The result is that overlaying the map with other maps, such as topography, roads, or even the national baseline map, may result in minor discrepancies that in some cases could cause interpretation difficulties.

We recommend that a regional mapping group be convened and make decisions about how best to distribute a regional map at 1:250,000 so that it is most useful to the participating countries. Most likely this will require agreement on a projection system that can be used for the regional map but which at the same time can be easily converted to a series of different national projections.

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Annex 1

Legend for the Central American Ecosystems Map

Legend for the Central American Ecosystems Map / Leyenda del Mapa de Ecosistemas de América Central

Code		UNESCO class	Clase de UNESCO	Country / País						
UNESCO	*Map legend*			*B*	*G*	*S*	*H*	*N*	*C*	*P*
lA1a(1)(a)	1, 1-1, 1-2	Tropical evergreen broad-leaved lowland forest, well-drained	Bosque tropical siempreverde latifoliado de tierras bajas, bien drenado					X	X	X
lA1a(1)(a)-VG	1-VG	Tropical evergreen broad-leaved lowland forest, well-drained, Valle del General variant (Costa Rica)	Bosque tropical siempreverde latifoliado de tierras bajas, bien drenado, variante de la Valle del General (Costa Rica)						X	
lA1a(1)(a)-ZA	1-ZA	Tropical evergreen broad-leaved lowland forest, well-drained, Atlantic Zone variant (Costa Rica)	Bosque tropical siempreverde latifoliado de tierras bajas, bien drenado, variante de la Zona Atlántica (Costa Rica)						X	
lA1a(1)(a)-CG	1-CG	Tropical evergreen broad-leaved lowland forest, well-drained, Central Costa Rica and Guanacaste variant	Bosque tropical siempreverde latifoliado de tierras bajas, bien drenado, variante de Guanacaste y Costa Rica Central						X	
lA1a(1)(a)-VT	1-VT	Tropical evergreen broad-leaved lowland forest, well-drained, *Vochysia-Terminalia* variant	Bosque tropical siempreverde latifoliado de tierras bajas, bien drenado, variante *Vochysia-Terminalia*	X						
lA1a(1)(a)-C	1-C	Tropical evergreen broad-leaved lowland forest, well-drained, *Calophyllum* variant	Bosque tropical siempreverde latifoliado de tierras bajas, bien drenado, variante *Calophyllum*	X						
lA1a(1)(a)-ST	1-ST	Tropical evergreen broad-leaved lowland forest, well-drained, *Simarouba-Terminalia* variant	Bosque tropical siempreverde latifoliado de tierras bajas, bien drenado, variante *Simarouba-Terminalia*	X						
lA1a(1)(a)K-r	2-r	Tropical evergreen broad-leaved lowland forest, well-drained on rolling karstic hills	Bosque tropical siempreverde latifoliado de tierras bajas, bien drenado en colinas cársticas onduladas	X						
lA1a(1)(a)K-s	2-s	Tropical evergreen broad-leaved lowland forest, well-drained on steep karstic hills	Bosque tropical siempreverde latifoliado de tierras bajas, bien drenado en colinas cársticas escarpadas	X					X	
lA1a(1)(b)	3, 3-2	Tropical evergreen broad-leaved lowland forest, moderately drained	Bosque tropical siempreverde latifoliado de tierras bajas, moderadamente drenado					X	X	
lA1a(1)(b)-PN	3-PN	Tropical evergreen broad-leaved lowland forest, moderately drained, Pacific North and Central Valley variant (Costa Rica)	Bosque tropical siempreverde latifoliado de tierras bajas, moderadamente drenado, variante del Pacífico Norte y de la Valle Central (Costa Rica)						X	
lA1a(1)(b)-VG	3-VG	Tropical evergreen broad-leaved lowland forest, moderately drained, Valle del General variant (Costa Rica)	Bosque tropical siempreverde latifoliado de tierras bajas, moderadamente drenado, variante de la Valle del General (Costa Rica)						X	
lA1a(1)(b)-ZA	3-ZA	Tropical evergreen broad-leaved lowland forest, moderately drained, Atlantic Zone variant (Costa Rica)	Bosque tropical siempreverde latifoliado de tierras bajas, moderadamente drenado, variante de la Zona Atlántica (Costa Rica)						X	
lA1a(1)(b)K	4	Tropical evergreen broad-leaved lowland forest, moderately drained on calcareous soils	Bosque tropical siempreverde latifoliado de tierras bajas, moderadamente drenado en suelos calcáreos	X						

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Legend for the Central American Ecosystems Map / Leyenda del Mapa de Ecosistemas de América Central *(cont.)*

Code		UNESCO class	Clase de UNESCO	Country / País						
UNESCO	*Map legend*			*B*	*G*	*S*	*H*	*N*	*C*	*P*
lA1a(1)(b)P	5	Tropical evergreen broad-leaved lowland forest, moderately drained on poor or sandy soils	Bosque tropical siempreverde latifoliado de tierras bajas, moderadamente drenado en suelos pobres o arenosos	X	X				X	
lA1b(1)	6, 6-1, 6-2	Tropical evergreen broad-leaved submontane forest	Bosque tropical siempreverde latifoliado, submontano	X	X			X		X
lA1b(1)-ND	6-ND	Tropical evergreen broad-leaved submontane forest, C. de Nombre de Dios variant	Bosque tropical siempreverde latifoliado, submontano, variante de la C. de Nombre de Dios						X	
lA1b(1)-CG	6-CG	Tropical evergreen broad-leaved submontane forest, Central Costa Rica and Guanacaste variant	Bosque tropical siempreverde latifoliado, submontano, variante de Guanacaste y Costa Rica Central						X	
lA1b(1)-VG	6-VG	Tropical evergreen broad-leaved submontane forest, Valle del General variant (Costa Rica)	Bosque tropical siempreverde latifoliado, submontano, variante de la Valle del General (Costa Rica)						X	
lA1b(1)-ZA	6-ZA	Tropical evergreen broad-leaved submontane forest, Atlantic Zone variant (Costa Rica)	Bosque tropical siempreverde latifoliado, submontano, variante de la Zona Atlántica (Costa Rica)						X	
lA1b(1)K-r	7-r	Tropical evergreen broad-leaved submontane forest on rolling karstic hills	Bosque tropical siempreverde latifoliado submontano en colinas cársticas onduladas	X						
lA1b(1)K-s	7-s	Tropical evergreen broad-leaved submontane forest on steep karstic hills	Bosque tropical siempreverde latifoliado submontano en colinas cársticas escarpadas	X						
lA1b(3)	8	Tropical evergreen broad-leaved submontane palm forest	Bosque tropical siempreverde latifoliado submontano de palma	X						
lA1c(1)	9, 9-1	Tropical evergreen broad-leaved lower-montane forest	Bosque tropical siempreverde latifoliado montano inferior	X	X		X	X		X
lA1c(1)-A	9-A	Tropical evergreen broad-leaved lower-montane forest, Sierra Agalta variant	Bosque tropical siempreverde latifoliado montano inferior, Variante de la Sierra Agalta				X			
lA1c(1)-ND	9-ND	Tropical evergreen broad-leaved lower-montane forest, C. de Nombre de Dios variant	Bosque tropical siempreverde latifoliado montano inferior, variante de la C. de Nombre de Dios				X			
lA1c(1)-CG	9-CG	Tropical evergreen broad-leaved lower-montane forest, Central Costa Rica and Guanacaste variant	Bosque tropical siempreverde latifoliado montano inferior, variante de Guanacaste y Costa Rica Central						X	
lA1c(1)-VG	9-VG	Tropical evergreen broad-leaved lower-montane forest, Valle del General variant (Costa Rica)	Bosque tropical siempreverde latifoliado montano inferior, variante de la Valle del General (Costa Rica)						X	
lA1c(1/2)-HCW	10-HCW	Tropical evergreen mixed lower-montane forest, Honduras Central West variant	Bosque tropical siempreverde mixto montano inferior, variante de Honduras Central Occidental				X			

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Legend for the Central American Ecosystems Map / Leyenda del Mapa de Ecosistemas de América Central *(cont.)*

Code		UNESCO class	Clase de UNESCO	Country / País						
UNESCO	*Map legend*			*B*	*G*	*S*	*H*	*N*	*C*	*P*
IA1c(1/2)-RP	10-RP	Tropical evergreen mixed lower-montane forest, Rio Plátano variant	Bosque tropical siempreverde mixto montano inferior, variante del Rio Plátano				X			
IA1c(4)	11	Tropical evergreen broad-leaved lower-montane forest with palms	Bosque tropical siempreverde latifoliado montano inferior con palmas	X						
IA1d(1)	12, 12-2	Tropical evergreen broad-leaved upper-montane forest	Bosque tropical siempreverde latifoliado montano superior							X
IA1d(1)-A	12-A	Tropical evergreen broad-leaved upper-montane forest, Sierra Agalta variant	Bosque tropical siempreverde latifoliado montano superior, Variante de la Sierra Agalta				X			
IA1d(1)K	12-K	Tropical evergreen broad-leaved upper-montane forest, karstic	Bosque tropical siempreverde latifoliado montano superior, cárstico				X			
IA1d(1)-CG	12-CG	Tropical evergreen broad-leaved upper-montane forest, Central Costa Rica and Guanacaste variant	Bosque tropical siempreverde latifoliado montano superior, variante de Guanacaste y Costa Rica Central						X	
IA1d(1/2)-HCW	14-HCW	Tropical evergreen broad-leaved upper-montane forest, Honduras Central West variant	Bosque tropical siempreverde latifoliado montano superior, variante de Honduras Central Occidental				X			
IA1d(1/2)-RP	14-RP	Tropical evergreen broad-leaved upper-montane forest, Rio Plátano variant	Bosque tropical siempreverde latifoliado montano superior, variante del Rio Plátano				X			
IA1d(1/2)-ND	14-ND	Tropical evergreen broad-leaved upper-montane forest, C. de Nombre de Dios variant	Bosque tropical siempreverde latifoliado montano superior, variante de la C. de Nombre de Dios				X			
IA1e(1)	15	Tropical evergreen broad-leaved altimontane forest	Bosque tropical siempreverde latifoliado, altimontano							X
IA1e(1)-A	15-A	Tropical evergreen broad-leaved altimontane forest, Sierra Agalta variant	Bosque tropical siempreverde latifoliado, altimontano, Variante de la Sierra Agalta				X			
IA1e(1)-ND	15-ND	Tropical evergreen broad-leaved altimontane forest, C. de Nombre de Dios variant	Bosque tropical siempreverde latifoliado, altimontano, variante de la C. de Nombre de Dios				X			
IA1e(1/2)-HCW	16-HCW	Tropical evergreen mixed altimontane forest, Honduras Central West variant	Bosque tropical siempreverde mixto, altimontano, variante de Honduras Central Occidental				X			
IA1f(2)	17, 17-2	Tropical evergreen broad-leaved occasionally flooded alluvial forest	Bosque tropical siempreverde latifoliado aluvial ocasionalmente inundado	X	X			X		X
IA1f(2)-PR	17-PR	Tropical evergreen broad-leaved occasionally flooded alluvial forest, *Prioria copaifera* variant	Bosque tropical siempreverde latifoliado aluvial ocasionalmente inundado, variante *Prioria copaifera*							X
IA1f(2)(a)K	17-K	Tropical evergreen broad-leaved occasionally flooded alluvial forest, on calcareous soils	Bosque tropical siempreverde latifoliado aluvial ocasionalmente inundado en suelos calcáreos	X						
IA1f(4)	18	Tropical evergreen broad-leaved alluvial gallery forest	Bosque tropical siempreverde latifoliado aluvial de galería					X		

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Legend for the Central American Ecosystems Map / Leyenda del Mapa de Ecosistemas de América Central *(cont.)*

Code		UNESCO class	Clase de UNESCO	Country / País						
UNESCO	*Map legend*			*B*	*G*	*S*	*H*	*N*	*C*	*P*
IA1g(1)(a)	19	Tropical evergreen broad-leaved lowland swamp forest	Bosque tropical siempreverde latifoliado pantanoso de tierras bajas	X				X		X
IA1g(1)(a)-VG	19-VG	Tropical evergreen broad-leaved lowland swamp forest, Valle del General variant	Bosque tropical siempreverde latifoliado pantanoso de tierras bajas, variante de la Valle del General (Costa Rica)						X	
IA1g(1)(a)-ZA	19-ZA	Tropical evergreen broad-leaved lowland swamp forest, Atlantic Zone variant (Costa Rica)	Bosque tropical siempreverde latifoliado pantanoso de tierras bajas, variante de la Zona Atlántica (Costa Rica)						X	
IA1g(1)(b)-C	20-C	Tropical evergreen broad-leaved permanently inundated lowland swamp forest, *Campnosperma panamensis* variant	Bosque tropical siempreverde latifoliado pantanoso permanentemente inundado de tierras bajas, variente *Campnosperma panamensis*							X
IA1g(1)(b)	20	Tropical evergreen broad-leaved permanently inundated lowland swamp forest	Bosque tropical siempreverde latifoliado pantanoso permanentemente inundado	X				X		X
IA1g(2)(b)-HC	21-HC-2	Tropical evergreen broad-leaved lowland swamp forest with palms, permanently inundated, Central Honduras variant (exists only as intervened)	Bosque tropical siempreverde latifoliado pantanoso de tierras bajas, permanentemente inundado, con palmas, variante de Honduras Central (intervenido solamente)				X			
IA1g(2)(b)-MA	21-M	Tropical evergreen broad-leaved lowland swamp forest with palm, permanently inundated, *Manicaria* variant	Bosque tropical siempreverde latifoliado pantanoso de tierras bajas, permanentemente inundado, con palmas, variante *Manicaria*	X						
IA2a(1)(a)	22	Tropical evergreen seasonal broad-leaved lowland forest, well-drained	Bosque tropical siempreverde estacional latifoliado de tierras bajas, bien drenado		X			X		
IA2a(1)(a)-A	22-A	Tropical evergreen seasonal broad-leaved lowland forest, well-drained, Sierra Agalta variant	Bosque tropical siempreverde estacional latifoliado de tierras bajas, bien drenado, variante de la Sierra Agalta				X			
IA2a(1)(a)-P	22-P	Tropical evergreen seasonal broad-leaved lowland forest, well-drained, P	Bosque tropical siempreverde estacional latifoliado de tierras bajas, bien drenado, P				X			
IA2a(1)(a)-M	22-M, 22-M-2	Tropical evergreen seasonal broad-leaved lowland forest, well-drained, Mosquitia variant	Bosque tropical siempreverde estacional latifoliado de tierras bajas, bien drenado, variante de la Mosquitia				X			
IA2a(1)(a)-ST	22-ST	Tropical evergreen seasonal broad-leaved lowland forest, well-drained, *Simaruba-Terminalia* variant	Bosque tropical siempreverde estacional latifoliado de tierras bajas, bien drenado, variante *Simaruba-Terminalia*	X						
IA2a(1)(a)-PN	22-PN	Tropical evergreen seasonal broad-leaved lowland forest, well-drained, Pacific North and Central Valley variant (Costa Rica)	Bosque tropical siempreverde estacional latifoliado de tierras bajas, bien drenado, variante del Pacífico Norte y de la Valle Central (Costa Rica)						X	

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Legend for the Central American Ecosystems Map / Leyenda del Mapa de Ecosistemas de América Central *(cont.)*

Code		UNESCO class	Clase de UNESCO	Country / País						
UNESCO	*Map legend*			*B*	*G*	*S*	*H*	*N*	*C*	*P*
IA2a(1)(a)-VR	22-VR	Tropical evergreen seasonal broad-leaved lowland forest, well-drained, VRTG	Bosque tropical siempreverde estacional latifoliado de tierras bajas, bien drenado, VRTG						X	
IA2a(1)(a)-VT	22-VIT	Tropical evergreen seasonal broad-leaved lowland forest, well-drained, *Virola-Terminalia* variant	Bosque tropical siempreverde estacional latifoliado de tierras bajas, bien drenado, variante *Virola-Terminalia*	X						
IA2a(1)(a)K-r	23-r	Tropical evergreen seasonal broad-leaved lowland forest, well-drained, on rolling karstic hills	Bosque tropical siempreverde estacional latifoliado de tierras bajas, en colinas cársticas onduladas	X	X					
IA2a(1)(a)K-s	23-s	Tropical evergreen seasonal broad-leaved lowland forest, well-drained, on steep karstic hills	Bosque tropical siempreverde estacional latifoliado de tierras bajas, bien drenado, en colinas cársticas escarpadas	X	X					
IA2a(1)(a)K-s-M	23-s-M	Tropical evergreen seasonal broad-leaved lowland forest, well-drained, on steep karstic hills, Mosquitia variant	Bosque tropical siempreverde estacional latifoliado de tierras bajas, bien drenado, en colinas cársticas escarpadas, variante de la Mosquitia				X			
IA2a(1/2)(a)	24	Tropical evergreen seasonal mixed lowland forest, well-drained	Bosque tropical siempreverde estacional mixto de tierras bajas, bien drenado	X						
IA2a(1/2)(a)K	25	Tropical evergreen seasonal mixed, well-drained forest, on calcareous soils	Bosques tropical siempreverde estacional mixto, bien drenado, en suelos calcáreos		X					
IA2a(1)(b)	26, 26-2	Tropical evergreen seasonal broad-leaved lowland forest, moderately drained	Bosque tropical siempreverde estacional latifoliado de tierras bajas, moderadamente drenado							X
IA2a(1)(b)S	27	Tropical evergreen seasonal broad-leaved lowland forest on poor or sandy soils	Bosque tropical siempreverde estacional latifoliado de tierras bajas, bien drenado, en suelos pobres o arenosos	X						
IA2a(1)(b)K	28	Tropical evergreen seasonal broad-leaved lowland forest on calcareous soils	Bosque siempreverde estacional latifoliado de tierras bajas en suelos calcáreos	X	X					
IA2a(1)(b)K-Y	28-NE	Tropical evergreen seasonal broad-leaved lowland forest on calcareous soils, Yucatán variant	Bosque tropical siempreverde estacional latifoliado de tierras bajas en suelos calcáreos, variante Yucatán	X						
IA2a(1)(b)K-TP	28-NW	Tropical evergreen seasonal broad-leaved lowland forest on calcareous soils, Tehuantepec-Petén variant	Bosque tropical siempreverde estacional latifoliado de tierras bajas en suelos calcáreos, variante Tehuantepec-Petén	X						
IA2a(1)(b)K-CE	28-CE	Tropical evergreen seasonal broad-leaved lowland forest on calcareous soils, Central Eastern variant	Bosque tropical siempreverde estacional latifoliado de tierras bajas en suelos calcáreos, variante Central Oriental	X						
IA2a(1)(b)K-CW	28-CW	Tropical evergreen seasonal broad-leaved lowland forest on calcareous soils, Central West variant	Bosque tropical siempreverde estacional latifoliado de tierras bajas en suelos calcáreos, variante Central Occidental	X						

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Legend for the Central American Ecosystems Map / Leyenda del Mapa de Ecosistemas de América Central *(cont.)*

Code		UNESCO class	Clase de UNESCO	Country / País						
UNESCO	*Map legend*			*B*	*G*	*S*	*H*	*N*	*C*	*P*
IA2a(1)(b)K-BR	28-BR	Tropical evergreen seasonal broad-leaved lowland forest on calcareous soils, Belize River variant	Bosque tropical siempreverde estacional latifoliado de tierras bajas en suelos calcáreos, variante del Río Belice	X						
IA2a(3)(b)K	29	Tropical evergreen seasonal broad-leaved lowland forest dominated with bamboo on calcareous soils	Bosque siempreverde estacional latifoliado de tierras bajas dominado por bambú, en suelos calcáreos		X					
IA2a(1/2)(b)	30	Tropical evergreen seasonal mixed lowland forest, moderately drained	Bosque tropical siempreverde estacional mixto de tierras bajas, moderadamente drenado							
IA2a(1/2)(b)-M	30-M	Tropical evergreen seasonal mixed lowland forest, moderately drained, *Pinus caribaea* Mosquitia variant	Bosques tropical siempreverde estacional mixto de tierras bajas, moderadamente drenado, variante *Pinus caribaea* de la Mosquitia				X			
IA2a(1/2)(b)-HC	30-HC-2	Tropical evergreen seasonal mixed lowland forest, moderately drained, Central Honduras variant (exists only as intervened)	Bosque tropical siempreverde estacional de tierras bajas, variante de Honduras Central (intervenido solamente)				X			
IA2a(2)(b)	31, 31-1, 31-2	Tropical evergreen seasonal needle-leaved lowland forest, moderately drained	Bosque tropical siempreverde estacional aciculifolia de tierras bajas, moderadamente drenado	X			X	X		
IA2a(2)(a)	32	Tropical evergreen seasonal needle-leaved lowland forest, well-drained	Bosque tropical siempreverde estacional aciculifolia de tierras bajas, bien drenado	X						
IA2a(2)(a)K-s	33-s	Tropical evergreen seasonal needle-leaved forest, well-drained, on steep karstic hills	Bosque tropical siempreverde estacional aciculifoliado, en colinas cársticas escarpadas		X					
IA2b(1)	34	Tropical evergreen seasonal broad-leaved submontane forest	Bosque tropical siempreverde estacional latifoliado, submontano		X	X		X		
IA2b(1)-VR	34-VR	Tropical evergreen seasonal broad-leaved submontane forest, VR and GT	Bosque tropical siempreverde estacional latifoliado submontano, VR y GT						X	
IA2b(1)-VT	34-VT	Tropical evergreen seasonal broad-leaved submontane forest, *Virola-Terminalia* variant	Bosque tropical siempreverde estacional latifoliado, submontano, variante *Virola-Terminalia*	X						
IA2b(1)-ST	34-ST	Tropical evergreen seasonal broad-leaved submontane forest, *Simarouba-Terminalia* variant	Bosque tropical siempreverde estacional latifoliado, submontano, variante *Simarouba-Terminalia*	X						
IA2b(1)(d)-L	34-l	Tropical evergreen seasonal broad-leaved submontane low forest	Bosque tropical siempreverde estacional latifoliado bajo, submontano	X						
IA2b(1)K-r	35-r	Tropical evergreen seasonal broad-leaved submontane forest on rolling karstic hills	Bosque tropical siempreverde estacional latifoliado submontano en colinas cársticas onduladas	X						
IA2b(1)K-s	35-s	Tropical evergreen seasonal broad-leaved submontane forest on steep karstic hills	Bosque tropical siempreverde estacional latifoliado submontano en colinas cársticas escarpadas	X						
IA2b(1/2)	36	Tropical evergreen seasonal mixed submontane forest	Bosque tropical siempreverde estacional mixto, submontano	X	X			X		

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Code		UNESCO class	Clase de UNESCO	Country / País						
UNESCO	*Map legend*			*B*	*G*	*S*	*H*	*N*	*C*	*P*
IA2b(2)	37, 37-2	Tropical evergreen seasonal needle-leaved submontane forest	Bosque tropical siempreverde estacional aciculifolia, submontano	X		X		X		
IA2c(1)	38	Tropical evergreen seasonal broad-leaved montane forest	Bosque tropical siempreverde estacional latifoliado montano inferior	X		X		X		
IA2c(1/2)	39	Tropical evergreen seasonal mixed montane forest	Bosque tropical siempreverde estacional mixto montano inferior		X					
IA2c(2)	40	Tropical evergreen seasonal needle-leaved montane forest	Bosque tropical siempreverde estacional aciculifolia montano inferior		X					
IA2d(1)	41	Tropical evergreen seasonal broad-leaved upper-montane forest	Bosque tropical siempreverde estacional latifoliado montano superior		X					
IA2d(1/2)	42	Tropical evergreen seasonal mixed upper-montane forest	Bosque tropical siempreverde estacional mixto montano superior		X					
IA2d(2)	43	Tropical evergreen seasonal needle-leaved upper-montane forest	Bosque tropical siempreverde estacional aciculifolia montano superior		X					
IA2e (1)	44	Tropical evergreen seasonal broad-leaved forest	Bosque tropical siempreverde estacional latifoliado altimontano		X					
IA2e(1/2)	45	Tropical evergreen seasonal mixed altimontane forest	Bosque tropical siempreverde estacional mixto altimontano		X					
IA2e(2)	46	Tropical evergreen seasonal needle-leaved altimontane forest	Bosque tropical siempreverde estacional aciculifolia altimontano		X					
IA2f(2)(a)	47	Tropical evergreen seasonal broad-leaved alluvial forest, occasionally inundated	Bosque tropical siempreverde estacional latifoliado aluvial de tierras bajas, ocasionalmente inundado	X				X		
IA2f(3)(a)	48-ES, 48-M	Tropical evergreen seasonal broad-leaved alluvial forest, seasonally inundated	Bosque tropical siempreverde estacional latifoliado aluvial de tierras bajas, estacionalmente inundado		X		X	X		
1A2f(3)(c)	49	Tropical evergreen seasonal alluvial forest, seasonally inundated, dominated by bamboo	Bosque tropical siempreverde estacional latifoliado aluvial de tierras bajas, estacionalmente inundado, dominado por bambú					X		
1A2f(4)(a)	50	Tropical evergreen seasonal broad-leaved alluvial gallery forest	Bosque tropical siempreverde estacional latifoliado aluvial de galería de tierras bajas					X		
IA2g(2)(a)	51	Tropical evergreen seasonal palm swamp forest	Bosque tropical siempreverde estacional de palmas de tierras bajas, pantanoso					X		
IA2g(1)(a)-T	52-T	Tropical evergreen seasonal broad-leaved lowland swamp forest, tall variant	Bosque tropical siempreverde estacional latifoliado pantanoso de tierras bajas, variante alto	X						
IA2g(1)(a)-Sh	52-Sh	Tropical evergreen seasonal broad-leaved lowland swamp forest, short tree variant	Bosque tropical siempreverde estacional latifoliado pantanoso de tierras bajas, variante árboles bajos	X						

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Legend for the Central American Ecosystems Map / Leyenda del Mapa de Ecosistemas de América Central *(cont.)*

Code		UNESCO class	Clase de UNESCO	Country / País						
UNESCO	*Map legend*			*B*	*G*	*S*	*H*	*N*	*C*	*P*
IA2g(1)(a)-SC	52-SC	Tropical evergreen seasonal broad-leaved lowland swamp forest, Stann Creek variant	Bosque tropical siempreverde estacional latifoliado pantanoso de tierras bajas, variante del Stann Creek	X						
IA2g(1)(a)-AC	52-AC	Tropical evergreen seasonal broad-leaved lowland swamp forest, Aguacaliente variant	Bosque tropical siempreverde estacional latifoliado pantanoso de tierras bajas, variante de Aguacaliente	X						
IA2g(2)(a)-M	53-M, 53-M-2	Tropical evergreen seasonal lowland broad-leaved palm swamp forest, Mosquitia variant	Bosque tropical siempreverde estacional latifoliado pantanoso de tierras bajas, dominado por palmas, variante de la Mosquitia				X			
IA2g(1)(a)	54	Tropical evergreen seasonal broad-leaved lowland swamp forest, seasonally inundated	Bosque tropical siempreverde estacional latifoliado pantanoso de tierras bajas, estacionalmente inundado		X					
IA2g(3)(a)	55	Tropical evergreen seasonal broad-leaved lowland swamp forest, seasonally inundated	Bosque tropical siempreverde estacional latifoliado pantanoso de tierras bajas, estacionalmente inundado		X					
IA3a(1)(a)	56, 56-1, 56-2	Tropical semi-deciduous broad-leaved well-drained lowland forest	Bosque tropical semidecíduo latifoliado de tierras bajas, bien drenado	X	X	X		X		X
IA3a(1)(a)-HCW	56-HCW	Tropical semi-deciduous broad-leaved lowland well-drained forest, Honduras Central West variant	Bosque semidecíduo latifoliado de tierras bajas, bien drenado, variante de Honduras Central Occidental				X			
IA3a(1)(a)-PNVC	56-PNVC	Tropical semi-deciduous broad-leaved lowland well-drained forest, Pacific North and Central Valley variant (Costa Rica)	Bosque semidecíduo latifoliado de tierras bajas, bien drenado, variante del Pacífico Norte y de la Valle Central (Costa Rica)						X	
IA3a(1)(a)K	56-CAR	Tropical semi-deciduous broad-leaved lowland well-drained forest, on karstic terrain, Caribbean Coast variant	Bosque semidecíduo latifoliado de tierras bajas, bien drenado, en terrenos cársticos, variante de la Costa Caribeña				X			
IA3a(1)(a)-ISL	56-ISL-2	Tropical semi-deciduous broad-leaved well-drained lowland forest with palms, Bay Islands variant (exists only as intervened)	Bosque semidecíduo latifoliado con palmas de tierras bajas, variante de las Islas de la Bahía (intervenido solamente)				X			
IA3a(3)(a)-ISL	57-ISL	Tropical semi-deciduous broad-leaved well-drained lowland forest with palm, Bay Islands variant (exists only as moderately intervened)	Bosque semidecíduo latifoliado con palmas de tierras bajas, variante de las Islas de la Bahía (moderadamente intervenido solamente)				X			
IA3a(2)(a)	58-2	Tropical semi-deciduous mixed well-drained lowland forest (exists only as intervened)	Bosque semidecíduo mixto de tierras bajas, bien drenado (intervenido solamente)				X			
IA3a(2)(a)-HC	58-HC-1, 58-HC-2	Tropical semi-deciduous mixed well-drained lowland forest, Honduras Central variant (exists only as intervened and moderately intervened)	Bosque semidecíduo mixto de tierras bajas, bien drenado, variante de Honduras Central, (solamente intervenido y moderadamente intervenido)		X		X			

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UNESCO	*Map legend*			*B*	*G*	*S*	*H*	*N*	*C*	*P*
IA3b(1)	59, 59-2	Tropical semi-deciduous broad-leaved submontane forest	Bosque tropical semidecíduo latifoliado, submontano		X		X			
IA3b(1)-NC	59-NC	Tropical semi-deciduous broad-leaved submontane forest, North Central Valley variant	Bosque tropical semidecíduo latifoliado, submontano, variante de la Valle Norte Central						X	
IA3b(2)	60	Tropical semi-deciduous mixed submontane forest	Bosque tropical semidecíduo mixto, submontano		X					
IA3c(1)	61	Tropical semi-deciduous broad-leaved lower montane forest	Bosque tropical semidecíduo latifoliado montano inferior		X					
IA3c(1)-PN	61-PN	Tropical semi-deciduous broad-leaved lower montane forest, Pacific North and Central Valley variant (Costa Rica)	Bosque tropical semidecíduo latifoliado montano inferior, variante del Pacífico Norte y de la Valle Central (Costa Rica)						X	
IA3c(1/2)	62	Tropical semi-deciduous mixed lower montane forest	Bosque tropical semidecíduo mixto montano inferior		X					
1A3f(4)(a)	63	Tropical semi-deciduous broad-leaved alluvial gallery forest	Bosque tropical semidecíduo latifoliado aluvial de galería de tierras bajas			X		X		
IA3g(a)	64	Tropical semi-deciduous broad-leaved lowland swamp forest	Bosque tropical semidecíduo latifoliado pantanoso de tierras bajas					X		
IA5a(1)	65	Caribbean mangrove forest on clay	Bosque de manglar del Caribe sobre sustrato limoso	X			X	X		
IA5a(2)	66	Caribbean mangrove forest on coraline sand	Bosque de manglar del Caribe sobre arena coralina					X		
IA5b(1)	67, 68, 68-2	Pacific mangrove forest on clay (previous classes have been combined)	Bosque de manglar del Pacífico sobre sustrato limoso			X	X	X		X
IB1a(1)	68, 68-2	Tropical deciduous broad-leaved lowland forest, well-drained, intervened	Bosque tropical decíduo latifoliado de tierras bajas, bien drenado, intervenido			X		X		X
IB1a(1)	69-PN, 69-2	Tropical deciduous broad-leaved lowland forest, well-drained, intervened (includes Costa Rican Northern Pacific variant)	Bosque tropical decíduo latifoliado de tierras bajas, bien drenado (incluye variante del Pacífico Norte en Costa Rica)		X	X		X	X	X
IB1a(2)	70	Tropical deciduous microphyllous lowland forest, well-drained	Bosque tropical decíduo microlatifoliado, bien drenado	X	X					
IIIA1b(1)(a)K	71	Seasonal evergreen broad-leaved lowland shrubland on calcareous soils	Arbustal siempreverde estacional latifoliado de tierras bajas en suelos calcáreos		X	X				
IIIA1a(1)(a)K-s	71-s	Evergreen broad-leaved shrubland on steep karstic hills	Arbustal siempreverde latifoliado bien drenado en colinas cársticas escarpadas	X						
IIIA1/2b(c)	72	Seasonal evergreen mixed lower montane shrubland	Arbustal siempreverde estacional mixto montano inferior		X	X	X	X		

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UNESCO	*Map legend*			*B*	*G*	*S*	*H*	*N*	*C*	*P*
IIIA1b(a)MI	73-MI	Evergreen broad-leaved lowland shrubland, well-drained, Miconia variant	Arbustal siempreverde latifoliado, de tierras bajas, bien drenado, variante Miconia	X						
IIIA1b(a)LE	74-L	Evergreen broad-leaved lowland shrubland, well-drained, dominated by Leguminous shrubs	Arbustal siempreverde latifoliado de tierras bajas dominado por arbustos Leguminosos	X						
IIIB1b(a)	75, 75-2	Deciduous broad-leaved lowland shrubland, well-drained	Arbustal decíduo latifoliado de tierras bajas, bien drenado	X	X	X	X	X		
IIIB1b(f)	76	Deciduous broad-leaved lowland riparian shrubland	Arbustal decíduo latifoliado ripario de tierras bajas	X						
IIIB1b(b)	77	Deciduous broad-leaved submontane shrubland, well-drained	Arbustal decíduo latifoliado submontano en suelos pobres, bien drenados	X						
IIIB2b(a)	78	Deciduous microphyllous lowland shrubland, well-drained	Arbustal decíduo microlatifoliado de tierras bajas, bien drenado		X					
IIIB1b(g)	79	Deciduous broad-leaved shrubland swamp with dispersed trees	Arbustal deciduo, latifoliado pantanoso con árboles dispersos		X					
IIIA1a	80	Evergreen shrubland swamp dominated by bamboo shrubs	Arbustal siempreverde de carrizal de bambú pantanoso		X					
VA1b(1)	81	Tall-grass savanna with evergreen broad-leaved trees	Sabana de graminoides altos con árboles latifoliados siempreverdes					X		
VA1e(1)	82	Tall-grass waterlogged savanna with evergreen broad-leaved trees and/or palms	Sabana de graminoides altos con árboles latifoliados siempreverdes y/o palmas, anegada				X	X		
VA2a(1)(1)(e)	83	Tropical savanna with broad-leaved trees, altimontane	Sabana con árboles latifoliados, altimontana						X	
VA2a(1)(1)(g)	84	Short-grass waterlogged savanna with broad-leaved trees	Sabana de graminoides cortos con árboles latifoliados, anegada							X
VA2a(1)(g)	85	Short-grass waterlogged savanna with broad-leaved trees	Sabana de graminoides cortos anegada con árboles latifoliados siempre verdes							X
VA2a(1)(2)	85, 85-2	Short-grass savanna with scattered needle-leaved trees	Sabana de graminoides cortos con árboles aciculifolias dispersos	X			X			
VA2a(1)(2)(g)-M	86-M	Short-grass waterlogged savanna with needle-leaved trees, Mosquitia variant	Sabana de graminoides cortos con árboles aciculifoliados, anegada, variante de la Mosquitia				X	X		
VA2b(2)	87	Short-grass savanna with deciduous shrubs	Sabana de graminoides cortos con arbustos decíduos	X		X		X	X	
VA2b(2)-PN	88-PN	Short-grass savanna with deciduous shrubs, Pacific North and Central Valley variant (Costa Rica)	Sabana de graminoides cortos con arbustos decíduos, variante del Pacífico Norte y de la Valle Central (Costa Rica)						X	

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VA2b(2)-VG	89-VG	Short-grass savanna with deciduous shrubs, Valle del General and Pacific South variant (Costa Rica)	Sabana de graminoides cortos con arbustos decíduos, variante de la Valle del General y del Pacífico Sur (Costa Rica)						X	
VA2b(6)(g)	90	Herbs and grass swamp with shrubs and/or palms	Herbazal pantanoso con gramíneas, palmas y/o arbustos		X					
VA2c(b/c)	91	Short-grass savanna without woody plants, submontane or montane	Sabana de graminoides cortos sin cobertura leñosa, submontano o montano					X		
VA2c(g)	92	Short-grass savanna without trees or shrubs, waterlogged	Sabana de graminoides cortos sin plantas leñosas, anegada	X				X		
VC2b	93	Tropical altimontane meadow or páramo	Vegetación de páramo, altimontano						X	X
VD1a	94, 94-2	Tall sedge swamp	Pantano de ciperáceas altas		X		X	X		X
VD1a(1)	95	*Eleocharis* marsh	Pantano de *Eleocharis*	X						
VE1a(1)	96	Marine salt marsh rich in succulents	Marisma con muchas plantas suculentas	X						
VE1a(2)	97	Salt meadow poor in succulents	Pradera salobre pobre en plantas suculentas				X			X
VF1c1-2	98-2	Fire-induced fern lowland thicket (exists only as intervened)	Herbazal de helechos, inducido por fuego, en tierras bajas (existe solamente como intervenido)	X					X	
VF3d	99	Episodical river bed formation	Formación episódica de cauce de río					X	X	
VIA	100	Scarcely vegetated rocks	Rocas con escasa vegetación		X	X				
VIAd	101	Scarcely vegetated lava flow	Flujo de lava con escasa vegetación			X		X	X	X
VIAe	102	Scarcely vegetated marine rocks	Rocas marinas con escasa vegetación						X	
VIA2	103	Scarcely vegetated scree	Lajar con escasa vegetación					X		
VIB1a(1)	104	Scarcely vegetated tropical dune and beaches	Duna y playa tropical con escasa vegetación		X	X		X	X	
VIB3a	105	Tropical coastal vegetation on very recent sediments, moderately drained	Vegetación tropical costera en suelos muy recientes, moderadamente drenado	X			X	X		X
VIB3aK	106	Coastal vegetation on karstic hills	Vegetación costera en colinas cársticas				X			
VIB3b	107	Coastal swamp vegetation on very recent sediments	Vegetación costera pantanosa en suelos muy recientes					X		
VIB3c	108	Intertidal or permanently emerged sand banks with scarce vegetation	Banco arenoso intermareal o permanentemente emergido con escasa vegetación							
VIB5	109, 110	Scarcely vegetated saline flat (previous classes combined)	Albina con escasa vegetación				X	X		X

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VIIB1a	111	Tropical freshwater reed-swamp formation	Carrizal pantanoso de agua dulce	X		X		X	X	X
VIIB4	112-VG	Tall-herbs lowland swamp (this subsumes a Costa Rican Valle del General variant that may appear as VIIB4-VG)	Pantano de hierbas altas de tierras bajas, variante de la Valle del General (Costa Rica)	X					X	
VIIB4-ZA	112-ZA	Tall-herbs lowland swamp, Atlantic Zone variant (Costa Rica)	Pantano de hierbas altas de tierras bajas, variante de la Zona Atlántica (Costa Rica)						X	
VIIE1a	114	Free-floating aquatic vegetation	Vegetación acuática libremente flotando				X			
SPA	115	Agro-productive system	Sistema agropecuario	X	X	X	X	X	X	X
SPC1	116	Aquaculture, shrimp farms and/or saltpans	Acuacultura, camaronera y/o salinera	X	X	X	X	X		X
SA1a(2)	119	Mid-watershed river	Río de cuenca media		X				X	
SA1a(3)(a)	120	River of the Pacific littoral	Río del litoral del Pacífico		X				X	
SA1a(3)(b)	121	River of the Caribbean littoral	Río del litoral del Caribe		X				X	
SA1b(1)	122, 123	Volcanic lake (previous classes combined)	Lago o laguna volcánico		X	X		X	X	
SA1b(2)	124	Tectonic lake	Lago o laguna tectónico		X		X	X	X	
SA1b(3)	125	Karstic lake	Lago o laguna cárstico		X					
SA1b(4)(a)	126	Freshwater lake of the Pacific littoral plain	Lago o laguna de agua dulce del litoral del Pacífico		X		X		X	
SA1b(4)(b)	127	Freshwater lake of the Caribbean littoral plain	Lago o laguna de agua dulce del litoral del Caribe		X				X	
SA1b(4)(c)	128	Freshwater lake on interior plain	Lago o laguna en una llanura del interior		X					
SA1b(5)	129	Predominantly brackish lake or canal of the Caribbean littoral plain	Lago o laguna o canal de agua salobre del Caribe				X	X		
SA1c(1)(a)	130	Open estuary of the Pacific	Estuario abierto del Pacífico				X	X	X	
SA1c(1)(b)	131	Open estuary of the Caribbean	Estuario abierto del Caribe					X		
SA1c(2)(a)	132	Semi-closed estuary of the Pacific	Estuario semicerrado del Pacífico		X			X	X	
SA1c(2)(b)	133	Semi-closed estuary of the Caribbean	Estuario semicerrado del Caribe					X	X	
SA1d(2)	134	Coral reef of the Caribbean	Arrecife coralino del Caribe	X			X			
SA2a	135	Reservoir	Embalse					X	X	
U1	136	Urban area	Área urbana	X	X	X		X		X
	137	Areas without satellite data coverage	Área sin cobertura de datos satelitares							

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