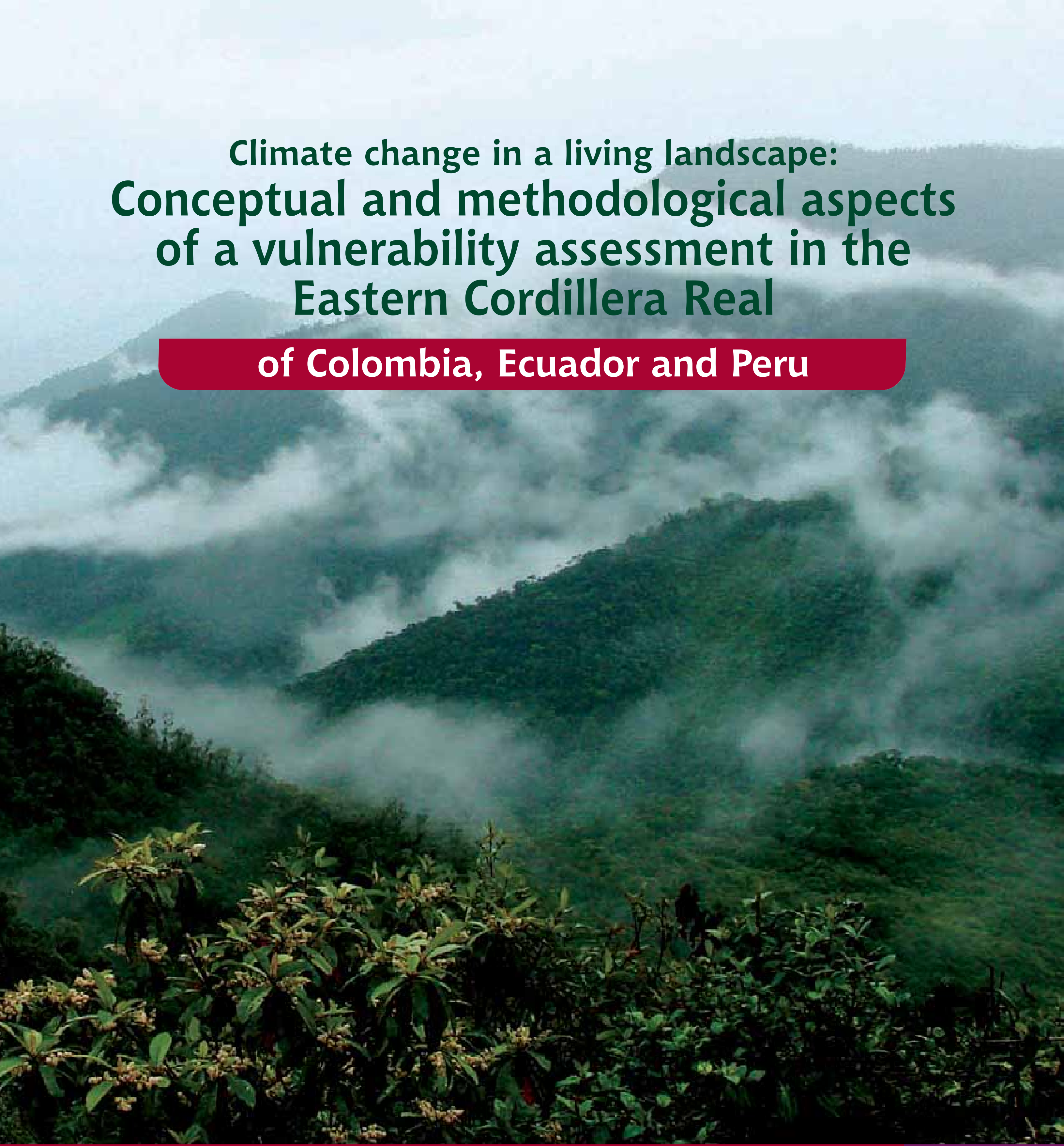

Climate change in a living landscape:

Conceptual and methodological aspects of a vulnerability assessment in the Eastern Cordillera Real

of Colombia, Ecuador and Peru

DFID Department for International Development

WWF

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Content

Introduction

The Eastern Cordillera Real (ECR) is one of the most biologically and culturally diverse ecoregions in the whole of the Northern Andes, and at the same time one of the most threatened from a multitude of human induced pressures. From 2006 to 2009, WWF in Peru and Colombia and Fundación Natura Ecuador developed a tri-national project in the ECR funded by the European Union that aimed to improve regional coordination, maintain the integrity of natural ecosystems and promote sustainable livelihoods. The project targeted actions that could contribute to reduce major conservation threats, including climate change and the urgent need to develop adaptation strategies. This work combined analysis and assessment of the vulnerability of ecological and social systems to climate change with a participatory process with local and national stakeholders for the development of adaptation strategies. The analytical work provided the technical information and framework for the dialogue and development of local and regional adaptation plans.

This document is a translated summary of the original publication resulting from this initiative: *Cambio climático en un paisaje vivo: Vulnerabilidad y adaptación en la Cordillera Real Oriental de Colombia, Ecuador y Perú* (WWF y Fundación Natura 2010). We have focused primarily on presenting the methodological aspects of the vulnerability analysis, providing information on Eastern Cordillera Real (ECR) to illustrate how we applied the Turner II *et al.* (2003) three-pronged framework for understanding vulnerability of a system to environmental change. The results of the combined vulnerability analyses (biological, hydrological and socio-economic) for the ECR demonstrate the need for actions oriented at maintaining the continued provision of ecosystem services as well as the biological and cultural riches of the region. Priority adaptation measures include actions to develop and strengthen the capacity and the production systems of the local communities and institutions, aiming to maintain and recover ecosystem resilience, strengthen a regional policy framework with considerations of vulnerability and adaptation to climate change and strengthen the capacity to generate and disseminate information necessary to increase citizen participation in decision making processes.

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Chapter 1

Determining vulnerability of Andean ecosystems to climate change: who is vulnerable to what?[1]

The annual number of climate-related disasters within the Andean Community of Nations between 2002 and 2006 doubled the figure reached between 1977 and 1981 (CAN 2008), a painful reminder of the fragility of mountain ecosystems. The increase in the frequency and intensity of extreme weather events in the tropical Andes leading to these disasters has been widely documented, but the consequences of these phenomena in the long term are still insufficiently understood. But despite the shortage of information on the latter, it is clear the imperative to develop climate change adaptation strategies at different scales aimed to maintain or even increase the resilience of ecosystems and local communities to the impacts of climate change. A significant increase in temperature and changes in precipitation patterns in the tropical Andes will likely result in

1. Adapted from: Naranjo, L.G. & C. F. Suárez. 2010. Determinación de la vulnerabilidad de ecosistemas andinos al cambio climático: quién es vulnerable a qué? Pp. 17-24 En: Naranjo, L.G. (Ed). Cambio climático en un paisaje vivo: vulnerabilidad y adaptación en la Cordillera Real Oriental de Colombia, Ecuador y Perú. Cali: Fundación Natura -WWF.

changes in the distribution of species and ecosystems expected to occur within the next century, and this will undoubtedly impair ecosystem integrity and the provision of ecosystem services for local communities (clean and reliable water resources, biodiversity, and local climate) and for the region as a whole (biodiversity, water and carbon) (Urrutia & Vuille 2009).

Developing adaptation measures to secure the biodiversity riches and the well being of the inhabitants of the tropical Andes for years to come requires understanding how vulnerable different systems in the region are to the impacts of climate change. This poses multiple challenges since the complexity of Andean biotic communities, the variety of socio-economic systems present throughout the region and the differential response to climate variation from place to place, due to the spatial heterogeneity of these mountains, impede a characterization of vulnerability applicable to the whole region. Consequently, the ECR assessment initiated with the review of the basic conceptual issues related to climate change.

Vulnerability: The definition of the term "vulnerability" is far from universal (Downing 2003), and scientists from different disciplines usually differ in their use of the term (Adger *et al.* 2004, Füssel 2005, 2007).According to the third assessment report of the Intergovernmental Panel on Climate Change (McCarthy *et al.* 2001), vulnerability is "the degree to which a system is susceptible to, or unable to cope with adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity." Following the tradition of the literature on risk, hazards, poverty and development, this definition interprets the final outcomes of climatic events as the result of a combination of hazards and the intrinsic vulnerability of a system (Downing & Pathwardan 2004).

The application of this definition revolves around the answers to several questions (Kienberger & Zeil 2005). First, it is necessary to identify the subject of vulnerability (**who** is vulnerable?) which, for a given area, can be a landscape, a local community, or a component of local biodiversity. In recent literature on vulnerability to climate change, the subject is usually referred to as a system.

The second question defines **to what** is vulnerable the system of interest (its exposure); depending on the local manifestation of change, a system can be more likely to be affected either directly and/or indirectly (a classic example is the exposure of coastal settlements to rising sea level). Therefore, the exposure index is related with the influences or stimuli affecting a system, it captures both the weather events and the climate patterns affecting the system, as well as overarching factors such as changes in the systems caused by climate-related impacts.

A third question addresses the sensitivity of the system in terms of the specific intrinsic properties that determine the degree to which it will respond to a change in climatic conditions. Sensitive systems readily react to climate variation and therefore can be perceptibly affected by small climate changes. Understanding system sensitivity also requires understanding the thresholds after which they begin to respond to climate variables, of the degree of adjustments the system can make and of the reversibility of the changes undergone by the system.

And last, but not least, it is important to understand under what circumstances (**when?**) will the system of interest become vulnerable, which means to analyze the basic properties and processes of society, economy, and policy, resulting in its capacity to adapt to new conditions (its resilience).

Turner II *et al.* (2003) developed a three-pronged framework for understanding vulnerability of a system to environmental change, which addresses these questions (Fig. 2). Their model illustrates the complex interactions involved in this kind of analysis and highlights the multiple factors that potentially affect the vulnerability of a particular system in a given location. This framework avoids uncoupling human and environmental conditions, allowing for the identification of linkages among the different variables determining the exposure, sensitivity and resilience of a system. This approach is particularly useful when dealing with stressors or threats of a compounding nature.

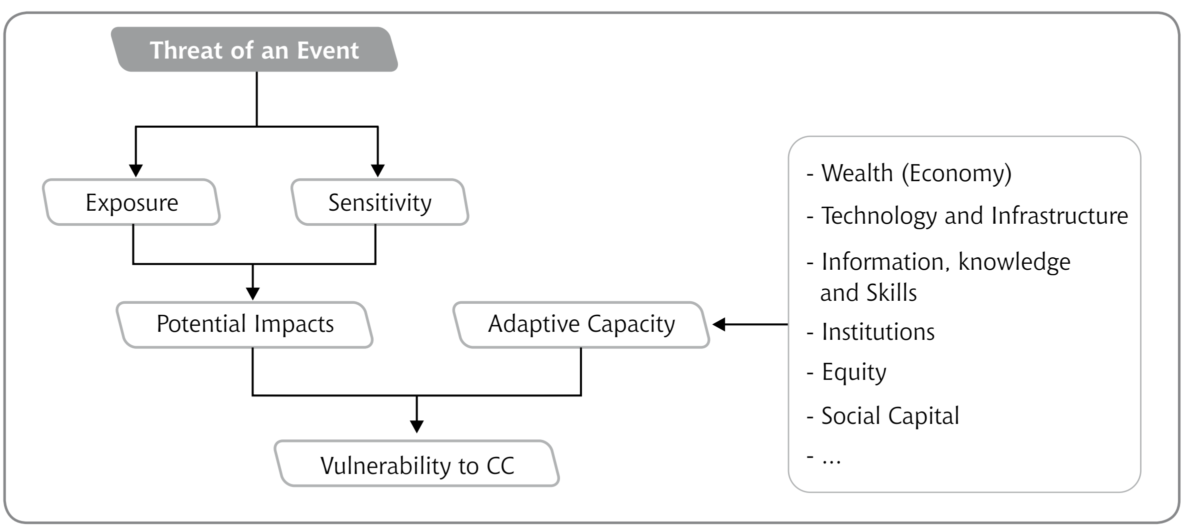

Figure 1. Conceptual model of climate change vulnerability included in the third report to IPCC (Ionescu *et al.*, 2005).

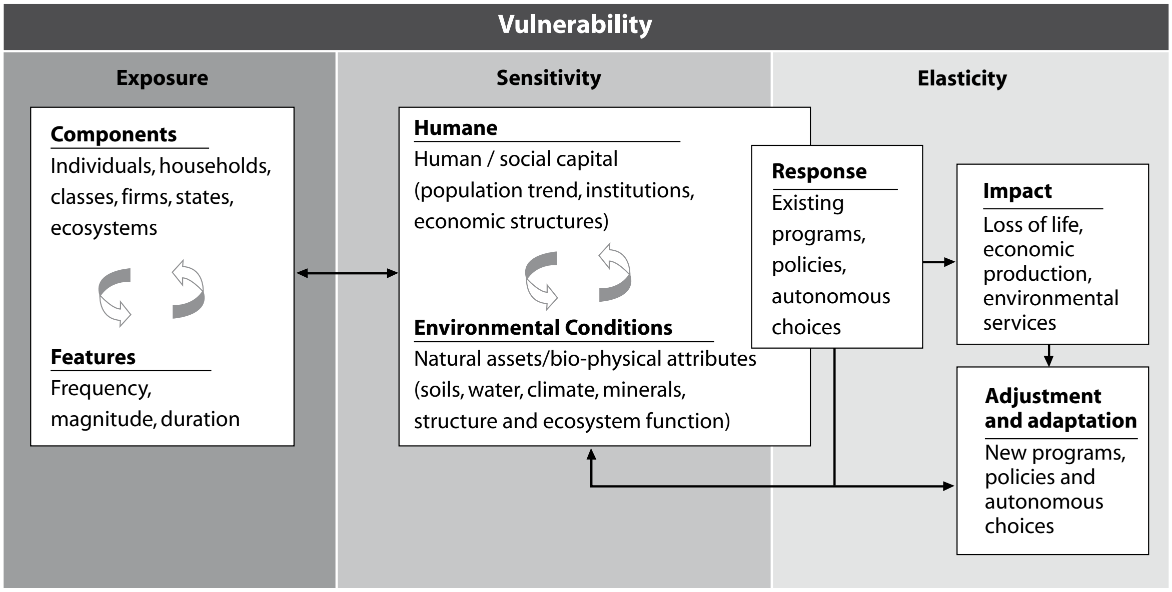

Figure 2. An integrated conceptual framework to assess vulnerability (adapted from Turner *et al*. 2003).

Adaptation reflects the capacity of a system to respond to a change, by using some of its properties to face external influences. Adaptation can be planned or autonomous. Planned adaptation is a change made anticipating climate variation, is an inner, strategic, conscious effort to increase the capacity of a system to face (or to avoid) the negative consequences of climate change. Therefore, and following Aguilar (2007), the vulnerability will increase as a function of the magnitude of a climate-related hazard, and will decrease as the resilience and the adaptive capacity of the system are strengthened. According to Turner II *et al.* (2003), one last set of variables that is necessary to tackle for an integrated assessment of vulnerability corresponds to coping, response, and the capacity of adjustment of the systems under consideration. Given the accelerated rate of change of climate variables, this is largely a matter of examining the social, political, economic and cultural environment of the systems analyzed, because most of the measures taken to maintain their resiliency will depend on societal responses. For instance, Schröeter (2007) takes into account three major components of the adaptive capacity of a system to global change: awareness, ability and action, which are determined, respectively, by equality and knowledge, technology and infrastructure, and flexibility and economic power. Both the components and their determinants vary from place to place, and therefore mapping socio-economic indicators at finer scales allow for an interpretation of the human component of the resilience of landscape units and ecosystems. Consequently mapping socio-economic variables at this same level of resolution is also necessary to gain insights into the human conditions that make a given system prone to suffer the impacts of climate change. Population density, wealth, education, economic structure, food systems and institutions are unevenly distributed in the region, and different groups and places within countries differ in their ability to cope with climate related impacts (Olmos 2001, Aguilar 2007, Downing & Ziervogel 2005).

Following this conceptual framework, a protocol to assess vulnerability to climate change at the sub-regional and local level in the Tropical Andes would involve at least seven steps:

1. Choosing the system of interest and the components that are more likely affected by climate change.
2. Obtaining historic meteorological and hydrological data sets pertaining to the scale of analysis.
3. Gathering secondary information on the spatial distribution of biophysical information of interest (e.g. vegetation cover, species ranges, distribution of crops and other rural production systems, etc.)
4. Downscaling regional models of future climate.
5. Modeling expected distribution of variables of interest under different climate change scenarios.
6. Map the socio-economic sensitivity and the adaptive capacity of the area of interest to major disturbances of their environments.
7. Estimate a vulnerability index combining the resulting overlays of ecological sensitivity (e.g. expected shifts of life zones, ecosystems and/or distribution of plants and animals) and the adaptive capacity as described above.

Vulnerability of Andean ecosystems to climate change

In terms of **exposure**, temperature has increased by 0.1ºC per decade since 1939 at the regional scale, and the rate of warming has tripled over the last 25 years (Vuille & Bradley 2000). Changes in precipitation are less consistent, but there is evidence of areas presenting either a significant increase or decrease of annual rainfall (Urrutia & Vuille 2009). The frequency of extreme weather events has also increased throughout (IPCC 2007). Despite these evidences, available information of current climate is still at a broad scale, and the process of downscaling it for specific sectors scale has only recently begun. However, it is evident that climate change at the regional level is already affecting a wide range of subjects, from populations and species to entire ecosystems and landscapes, from individual households to communities, and from firms to economic sectors.

The **sensitivity** of all these subjects to climate change stems from the most prominent ecological feature of the Tropical Andes, that is, the spatial heterogeneity of these mountains (see for example, WWF 2001). Ecosystem replacement along both altitudinal and latitudinal gradients is paramount throughout the region, and results in complex mosaics composed of relatively small landscape units that, because of their size, can be severely affected by climate change and extreme weather events. For this reason, modeling the spatial distribution of life zones, ecosystems, hydrological resources and species at a finer scale using downscaled climate variables is a necessity if one wants to understand how sensitive a given ecological or socio-economic system is from a biophysical perspective.

Resilience. As a whole, Andean socio-economic systems are particularly sensitive given the high levels of poverty in the region, as poverty limits the adaptive capabilities of an area (Watson *et al.* 1998), and as Ribot (1996) pointed out, inequality and marginalization are important determinants of vulnerability.

All the provinces of the Andean countries suffered at least one hydro-meteorological event between 1970 and 2007 (CAN 2008), and the effects of such events as well as of the regional trends of climate change are manifold. Increasing temperature has caused the acceleration in the loss of snow caps and glaciers throughout the region (IPCC 2007), which in turn has led to changes in the seasonal pattern and amount of runoff, affecting water resource availability and hydropower (Kundzewitz 2007). Changes in rainfall timing and intensity have resulted in increased frequency, intensity and scope of droughts or floods, with the resulting losses of agricultural crops and human lives. This makes it necessary to carry out regional and local assessments of ecosystem services in relation to climate variables, as the vulnerability of socio-economic systems will be largely determined by the availability of the resource base upon which they depend.

Although the impacts of regional and local climate change on specific components of ecological systems are still poorly understood, shifts in species distribution and both reduction and/or increase of natural ecosystems are likely to result. Increasing temperatures drive the upward migration of plant communities which may drive changes in the ranges of many animal and plant species adapted to specific habitats that occupy a narrow range along altitudinal and latitudinal climatic gradients (Epstein *et al.* 1998, Relman *et al.* 2008).

Chapter 2

Vulnerability analysis methodology for the Eastern Cordillera Real[2]

Area of study

The Eastern Cordillera Real (ECR) extends from the eastern slopes of the Colombian Massif to the Abra de Porculla 6° S in Peru. This region occupies 109,400 km^2 and includes the mountains of the Amazon watershed between a spot elevation of 300 m and the watershed to the Pacific slope. The rugged topography of the range leads to a complex network of rivers, which corresponds to seven large basins (Table 1, Figure 3).

Evidence of climate change in the survey area

Changes are showing in the Andean region both in temperature and precipitation levels and frequency of extreme events, especially more intense rainfall and strong and short winds (Soto, 2008). High mountain ecosystems

2. Adapted from: Hernández, O.L., C.F. Suárez & L.G. G. Naranjo. 2010. Vulnerabilidad al Cambio Climático en la Cordillera Real Oriental (Colombia, Ecuador y Perú). Pp. 25-64 En: Naranjo, L.G. (Ed). Cambio climático en un paisaje vivo: vulnerabilidad y adaptación en la Cordillera Real Oriental de Colombia, Ecuador y Perú. Cali: Fundación Natura -WWF.

Table 1. Extension of the watersheds in the study area.

Watershed	Area (Km²)	Watershed	Area (Km²)
Caqueta	7,616.90	Santiago	14,058.91
Putumayo	19,802.31	Zamora/Cenepa	23,919.82
Napo	9,837.05	Marañon	15,543.72
Pastaza	1,623.65	TOTAL	109,401.72

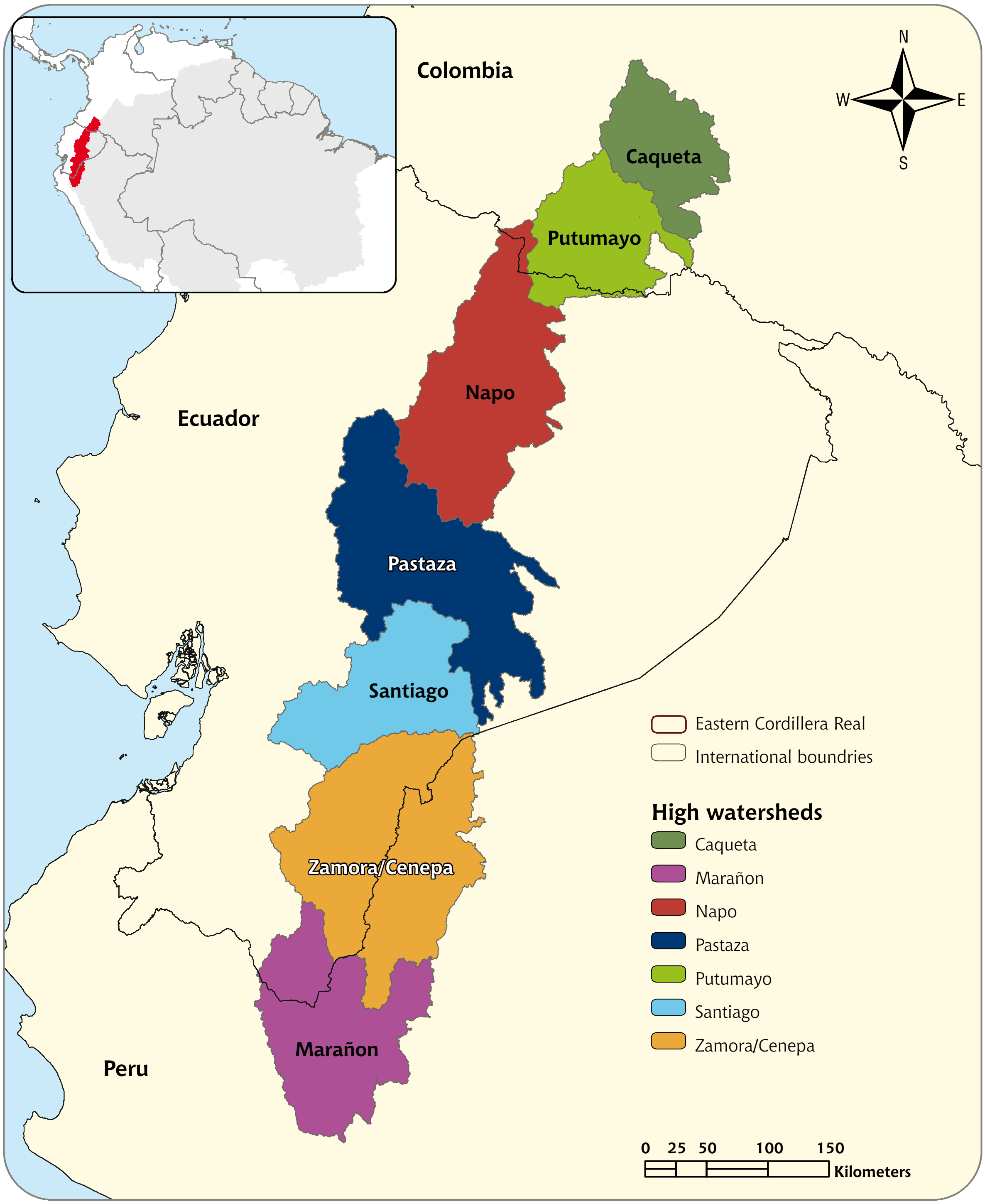

Figure 3. Study area and upper watershed.

as the glaciers of Colombia, Ecuador and Peru have had unprecedented declines in recent decades and most of them would be destined to disappear in a period of less than 30 years. According to the first national communication on climate change in Colombia (Ideam, 2001), it is confirmed that during the period from 1961 to 1990 the average air temperature in Colombia increased at a rate of 0.1 to 0.2°C per decade, while the annual rainfall experienced changes between -4% and +6% in different regions. In Ecuador, the measurement of changes in average temperature shows an increasing trend of 1.5° Cover the period from 1930 to 1993, with higher evidence of this change in the inter-Andean region compared to the coastal region (National Committee on Climate, 2001). The trend in rainfall is very irregular, with a greater inclination to decline. Finally, in Peru in the last 50 years there has been an increase in the maximum temperature of about 1.3°C (0.24°C per decade) and a general decrease in precipitation of 3% (National Environmental Council, 2001). Locally, there is a similar trend of temperature increase between 1989 and 2005.

The region of the ECR has endured a series of climatic anomalies with unusual intensity and frequency in the historical record of our time. Storms, floods and landslides, mainly related to events of the El Niño weather phenomenon, have hit the three countries thereby producing local economic losses as well as loss of human lives. According to an analysis of the rainfall recorded in the meteorological stations of the ECR, a slight increase in the standard deviation of monthly data is clear for the past three decades, which means an increase of the difference in the amount of rainfall between the dry and wet months.

A climate change vulnerability assessment is important to respond to future risks. For our evaluation of the Eastern Cordillera Real we have followed, in general terms, the points outlined in the protocol proposed in the previous section from the conceptual model integrated Turner II *et al.* (2003), considering the sensitivity systems and criteria defined by Intergovernmental Panel on Climate Change (IPCC) (Table 2).

Exposure

For our analysis of exposure, we used the following variables: ecosystems, species and water resources, as well as changing weather conditions which these attributes will face under future climate scenarios. These scenarios were generated by the Ministry of Environment of Ecuador (MAE, 2008) through the regional circulation model Precis, a regional modeling system developed by the Hadley Centre in England, using the ECHAM4 model for the A2 and B2 scenarios. We consider ECHAM4 model changes in temperature, precipitation and humidity

Table 2. Elements of analysis of vulnerability to climate change from the IPCC definition.

System		Sensitivity Criteria
Biodiversity	Climatic niche of species of birds and plants	Change in the assembly of the species analyzed
	Life Zones	Change in the distribution of life zones
Hydrology	Water balance	Change in runoff

and the scenarios A2 and B2 for the decades of 2030 and 2050.

In the case of species, we have assumed the exposure variables used by Cuesta *et al.* (2006), obtained from the TYN SC 2.0 database (Mitchell *et al.*, 2004), HadCM3 model, A2 and B2 scenarios for decade of 2050. Assuming that the A2 and B2 scenarios are similar to the reality of developing countries, i.e. a steady growth of its population and fragmented development in technology, and also taking into account differences in terms of emissions (Stage A2 - pessimistic and B2 -optimistic), we performed analysis in relation to these estimates. However, it should be noted that these scenarios cannot be considered forecasts as they have many uncertainties.

Sensitivity

We analyzed, for each system, its response to climate change scenarios. Thus, we took into account the change in the distribution of life zones, the change in species assemblage as an effect of temperature change and humidity change in runoff (sensitivity criteria for ecosystems, species and water resources) in response to projected changes in temperature, precipitation and humidity.

System 1: Biodiversity

The overall sensitivity for biodiversity is the product of the sum of the areas which are sensitive for species and areas which are sensitive for life zones in each scenario (A2 and B2). These areas were reclassified by map algebra into one category in order to calculate the sensitivity.

As proxies of ecosystems we took Holdridge's (1967) life zones as a starting point for our analysis. Under this system, certain groups of ecosystems or plant associations correspond to ranges of temperature, precipitation and humidity, so that divisions of these balanced climatic parameters can be defined in order to group them into life zones. The Holdridge life zones are a model of potential areas, as the current and projected areas affected are not taken into account.

Using the Bioclim layer of temperature and precipitation (Hijmans *et al.*, 2005) we modeled the Holdridge life zones for the current period and for the scenarios A2 and B2 of climate change. In order to do so, we averaged the estimated values for the years 2021-2030 and the years 2051-2060 and applied the classification of Holdridge adjusted to the study area (Table 3).

The sensitivity to climate change of a region in terms of life zones is given by the potential change in their geographical distribution. Areas with drastic changes in climate variables represent potential changes in life zones, which in turn represent areas with varying degrees of sensitivity. To select areas of greatest change in the ECR, we made a rough map which compares the life zones in the year 2030 and the present. We additionally did the same analysis comparing the life zones in 2050 and 2030 to locate areas with differences attributable to the effects of climate change in each scenario.

Table 3. Adjustment ranges for the calculation of life zones.

Upper Range	Elevation		Temperature	Precipitation	Humidity provinces (Ombrothermal Index - Io)	
1	0 – 1100	Basal	< 1.5	< 62.5	< 0.1	Ultra – hyper - arid
2	1100 – 2100	Sub - Andean	1.5 – 3	62.5 – 125	0.1 – 0.3	Hyper - arid
3	2100 – 3200	Andean	3 – 12	125 – 250	0.3 – 1	Arid
4	>3200	Paramo	12 – 24	250 – 500	1 – 2	Semiarid
5			> 24	500 – 1000	2 – 3.6	Dry
6				1000 – 2000	3.6 – 6	Subhumid
7				2000 – 4000	6 – 12	Wet
8				4000 – 8000	12 – 24	Hyper humid
9					> 24	Ultra – hyper –humid

On the other hand, the sensitivity of birds and plants to climate change was assumed as the potential degree of response in their geographical distribution. Thus, modeling of the climate niches of species allowed to determine areas which are more sensitive than others, from the estimated number of species that could change their distribution in response to climate change.

For the analysis of the Eastern Cordillera Real we took as surrogates for biodiversity the Maxent modeling (Phillips *et al*., 2006)[3] made by Cuesta *et al*. (2006) about the expected distribution for the year 2050 and the current distribution of 42 species of birds and 47 species of vascular plants in the northern Andes to the A2 and B2 scenarios of climate change of the HadCM3. Several of these species have characteristics that make them good indicators of diversity. Their time and mode of radiation is related to the uplift of the Andes and the Pleistocene climatic changes, their distribution patterns have a high replacement level throughout the environmental gradients within the region, several species are endemic and some are in some category of threat.

From these models, we evaluated the potential impact of climate change by analyzing the spatial patterns of change in relation to the different climate scenarios, according to Thuiller *et al*. (2005) and Broennimann *et al*. (2006). To do this, we took the spatial patterns of species generated by Cuesta *et al*. (2006) and quantified the number and percentage of species absent (loss) or new (gain) for each pixel in future climatic conditions. Thus, we estimated the turnover rate of the species under the assumption that a species can reach any area with suitable environmental conditions (universal dispersion) and the current vegetation cover is maintained over time, using the formula:

$$T = \frac{(G + L)}{(SR + G)} x100 \qquad [1]$$

Where:
T: volume of species;
G: gain of species;
L: loss of species;
SR: species richness present.

3. It is one of the global climate models of regulation.

A value of 0 indicates that the assemblage of species does not change (*i.e.*, no loss or gain of species), while 100 indicates that the assemblage of species is completely different in the new conditions. According to the change in the assembly (T) of species sensitivity thresholds were proposed, which were divided into four ranges (using quintiles) for both birds and to plants in each scenario. To select the most sensitive sites for each group we identified the highest quintiles, then added the most sensitive areas for each group of species in each scenario.

System 2: Hydrology

Water resources sensitivity is given by the proportional change (%) in todays total water supply compared to periods 2030 and 2050, as expressed in formula 2:

$$Sensitivity = \frac{Q_r}{_{Current}Q} x100 \quad [2]$$

Where:
Qr is the reference water supply projected by 2030 and 2050, expressed in flow m^3/sec.
$Q_{current}$ is the current Water supply flow, expressed in m^3/sec.

Methodologically, in order to estimate the current and future water supply we used the proposal made by the Soil Conservation Service (SCS, 1964) included in the *National Engineering Handbook* (2004) and its application, using tools of Geographic Information Systems (GIS) devised by Castillo *et al.* (2007).This tool relates precipitation with hydrological soil complex and prior moisture condition to establish the actual direct runoff. To estimate future supply, similar conditions of soil and vegetation cover over the current state are assumed,and the differences of precipitation are established according to the climate change scenarios (ECHAM4 model, A2 and B2, MAE, 2008), as change factor in water balance (Figure 4).

Runoff (Pe)[4] is the amount of water after a rain, which flows, drains or trickles over the soil surface. The runoff flows into streams, which increase their volume with water coming from faraway places and decrease soon after the rain ends. The excess water from the rains that fails to enter the soil flows over the surface of the earth, depending on various factors such as land use, vegetation cover, management practices, hydrologic soil group and precipitation. Runoff is calculated as:

$$Pe = \frac{(Pi - 0.2\ S)^2}{(Pi + 0.8\ S)} \quad [3]$$

Where:
Pe: Runoff in mm;
Pi: daily rainfall in mm;
S: Maximum retention in the watershed in mm.

4. The value of precipitation for the formula *Pe* is daily, however this balance is to have multi-year average monthly precipitation.

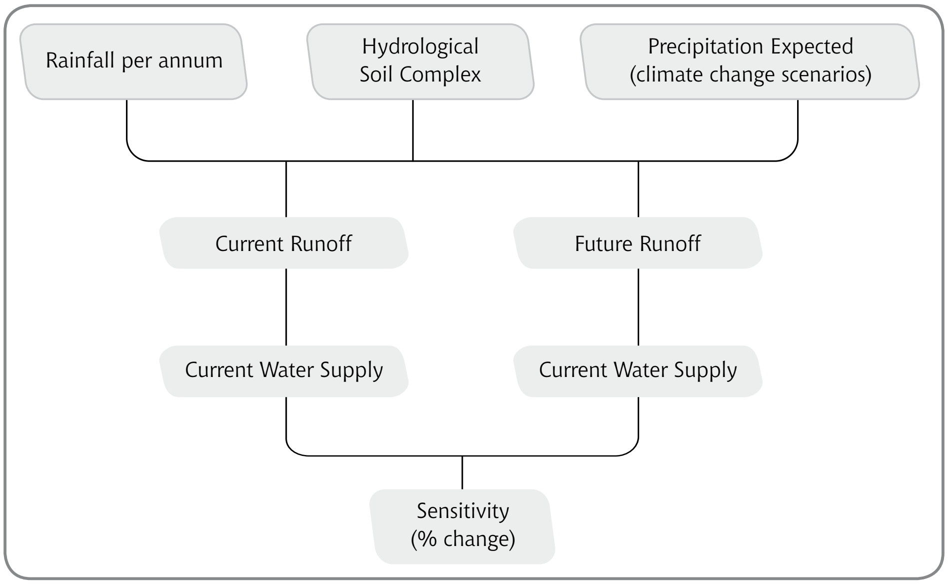

Figure 4. Model for sensitivity of water resources.

Equation 4 has a limitation that is the estimation of S, but it generally allows a good approximation of Q to watersheds by land use. The value of S is equal to the shelf capacity of the soil. S was defined according to the Curve Number (CN), described below according to:

$$S = \left(\frac{2540}{CN} - 25.4\right) \quad [4]$$

Water supply

Taking into account the expression of runoff, expressed in terms of water depth in millimeters, Q is cleared, which determines the surface water supply for each period of aggregation, which is monthly in this case.

$$Y = \frac{Q \; x \; T}{A \; x \; 10^3} \quad [5]$$

Where
And is the surface runoff in mm;
Q is the total monthly flow m^3/sec;
T is the number of seconds in a month;
A is the area of the basin regarding the hydrometric station.

$$Q = \frac{Y \; x \; A \; x \; 10^3}{T} \quad [6]$$

Adaptative Capacity Index

Adaptability refers to the ability to evolve and adapt to a changing environment. Natural and human systems can interact to overcome the changes. This adaptation is strengthened by the potential of available resources in a given area to generate new processes or implement new techniques (Aguilar, 2007; Sietchiping, 2006). Similarly, the IPCC (2007) states that “The ability to adapt is dynamic and is influenced by the productive base of society, in particular, the assets of natural and manmade capital, networks and social benefits, human capital and institutions, governance, national income, health and technology. It is also influenced by a variety of climatic and non-climatic stress factors, as well as development policies".

Under this premise, and with reference to the IPCC Technical Paper V (2002), on climate change and biodiversity, which states that the ability of countries to implement adaptation activities is related to the consideration of economic, social and environmental aspects, we have developed the following indicators that continue the previous guidelines. Thus, a true picture is portrayed of the conditions of adaptation in the ECR (Figure 5).

Calculation of socioeconomic variables

Socioeconomic variables are measured by the political-administrative divisions of each country in Level 3. We used information from rural population (also defined as the rest) of the most recent census in each country: 2005 for the Colombian municipalities, 2001 for the cantons in Ecuador and 2005 for the provinces in Peru (respectively, Dane[5] 2005, INEC[6] 2001, INEI[7] 2005). Data of Unsatisfied Basic Needs (NBI) for Ecuador was provided by TNC and for Peru information was taken from the Poverty Map of 1996. Data were standardized or normalized from 0 to 100 to make the calculations socioeconomic index (ISE), which is based on the following relationship for calculation:

$$ISE = \frac{Dp+In+Te+An+NBI}{5} \quad [7]$$

Where:

ISE, is the socioeconomic index;
Dp, is the population density;
In, the number of infants and children given by the population under 10 years;
Te, is the number of older adults or seniors over 65 years;
An, is the number of people who are illiterate;
NBI, is the index of unsatisfied basic needs.

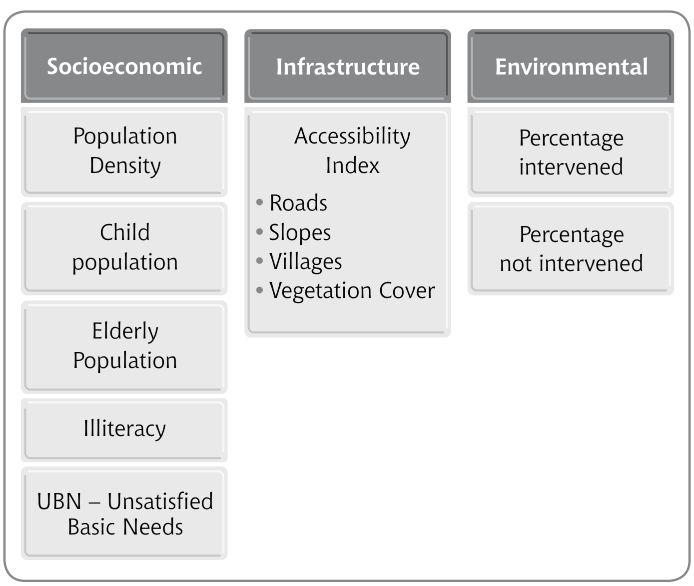

Figure 5. Themes and variables used in the current adaptation capacity of the ECR.

Infrastructure

Infrastructure is a factor which, the same as others, can have several interpretations, depending on the perspective from which it is analyzed, because it can help or hinder the implementation of activities addressing the reduction of vulnerability of the systems analyzed. The existence of a road or an area easily

5. Dane: National Bureau of Statistics of Colombia.
6. NICE: National Institute of Statistics and Censuses of Ecuador.
7. INEI: National Institute of Statistics and Informatics of Peru.

accessible, therefore, could facilitate the intervention and subsequent environmental degradation, thus making it an element that restricts the ability of adaptation (negative element). Moreover, other factors must be included in this analysis, such as the existence and operation of monitoring systems in biodiversity, or early warning systems, that ideally take into account indicators which give an insight into the sensitivity and changes related to climatic variables. These would be items that promote adaptation capacity (positive). However, these initiatives are null and do not have adequate information; this is why they were not taken into account in the end. Therefore we have proposed an accessibility index for assessing adaptation capacity in the context of infrastructure.

Environmental aspects

We selected two indicators of the implications of human activities on natural resources. When interpreted in the context of adaptation capacity, they represent a quantitative approximation of how much human beings can do for or against biodiversity and environmental services.

- *Percentage intervened,* given as the extent of transformed ecosystems in relation to a particular area, which in this case are the political-administrative divisions.
- *Percentage unprotected,* defined as the degree to which an administrative unit does not have conservation areas. It is reflected in relation to the extension of each administrative unit located geographically.

Calculation of the current adaptive capacity index

After doing the analysis described above, we averaged the standardized values of the three variables (socio-economic, infrastructure and environmental) for the rate of current capacity of the ECR, according to equation 8.

$$ICA = \frac{ISE+II+IA}{3} \quad [8]$$

Identification of vulnerability

The grouping of sensitivity with the index of adaptive capacity, provides scenarios that allow a view of vulnerability in the Eastern Cordillera Real (Table 4). Thus, we have determined four scenarios of vulnerability according to the proposal of Downing (2003), taking into account the degree of risk / climate impacts, previously classified in high and low; adaptive capacity classified as High, Medium and Low; and the identification of the high-risk group as vulnerable communities.

Table 4. Grouping climatic risks and adaptive capacity.

	Adaptation Capacity		
Risks	Low	Medium	High
High	Areas of high vulnerability	Areas of medium vulnerability	Areas of low vulnerability
Low	High residual risks	Low residual risk	Sustainability

Main conclusions of the analysis made in ECR

Due to limitations in available data and analysis procedures, the results of the analysis presented have a considerable margin of uncertainty, so the interpretations that emerge from such analysis should be taken as preliminary. However, in accordance with the precautionary principle, it is urgent to initiate development of adaptation measures for the most sensitive areas, with less adaptive capacity or which are more vulnerable, so they can respond to the new challenges posed by the current trends in climate change. In order to guide the participatory construction of local, national and regional adaptation to the ECR, the main conclusions of this analysis are presented below:

- A gradual increase in the average monthly temperature in the ECR of up to 2ºC is expected for the year 2099.
- The modeling of precipitation shows a slight trend to increase in the ECR, but with significant local variations from -20 to 60% and considerable variations from year to year.
- The only evident trend in precipitation change is the continued increase for the upper basin of the Pastaza River in Ecuador.
- The greatest variation in the distribution of life zones of the ECR would be held in the Upper Pastaza River in Ecuador. The upper reaches of the rivers Napo and Caqueta have similar trends which are also close to 50% change in the extent of the life zones.
- Nine life zones may increase their extension under the A2 scenario and 10 under the B2 scenario by 2030, while nine others would decrease by 2050 under the A2 scenario and eight under the B2 scenario (Table 5, Fig 6).

- Desert scrubs and dry forests are the only life zones which tend to increase surface for both scenarios in the two periods considered. Glaciers, the very humid Andean forest and the Andean rainforest would tend to decrease under both climate change scenarios.
- Of the fifteen life zones represented in the existing protected areas in the ECR, seven increased in area over 100% and another five areas have decreased in comparatively lower proportions against the two climate change scenarios.
- The values of expected change in species assemblages in the ECR reaches the highest values in the upper basins of the Napo and Pastaza rivers for the two climate change scenarios.
- Levels of sensitivity of the species considered surely underestimate the impact the variations on the composition and structure of biotic communities of the ECR could have, since the assumption of a specific response to changes in the individual climatic niche of the species does not take into account the consequences which the change an organism's distribution could have on the populations of those species with which it interacts.
- The highest values of biodiversity sensitivity of the system correspond to the Pastaza basin in both scenarios. Much more marked changes occur in the basins of the Putumayo, Santiago / Cenepa and Marañon against the A2 and the Napo and Caqueta basins reach their highest values of sensitivity in B2 scenario.
- Estimation of surface water supply revealed that the Santiago river basin (upstream of the Marañon River) is the Eastern Cordillera Real's sub – basin with lowest water levels. The basins of the rivers Zamora and Putumayo, at Bomboiza and Angosturas, are the stations that have the highest flows.
- The expected variations in river flows over the ECR for the years 2030 and 2060 are directly related to the variation in rainfall.
- The sensitivity of the sub – basins shows different trends in the two scenarios. Some of them are positive and some negative.
- Improved relations of expected water yield in liters / sec / km^2 can be evidenced in the basins of the Caqueta, Putumayo and Zamora rivers. In general, no significant changes are found between the two periods evaluated, except for the basins of Pastaza and Santiago, where yields improved (Figure 7).
- The upper basins of the Caqueta, Putumayo, Pastaza and Marañon rivers are moderately vulnerable to the two scenarios (A2 and B2), while those of the Napo Zamora / Cenepa, Santiago and Marañon are more vulnerable to the first of these two scenarios (Figure 6).

Table 5. List of sensitive and vulnerable sites in the ECR for the Biodiversity System.

Watershed	Scenario A2	Scenario B2
Caqueta	1. PuraceCorridor - Guacharos and Serrania de los Churumbelos (Municipalities of San Agustin, Santa Rosa and Piamonte) 2. Doña Juana - CascabelVolcanic Complex (municipalities of Santa Rosa and San Francisco)	1. PuraceCorridor - Guacharos and Serrania de los Churumbelos (municipalities of San Agustin, Santa Rosa and Piamonte) 2. Doña Juana-CascabelVolcanic Complex (municipalities of Santa Rosa and San Francisco)
Putumayo	1. Source of the Putumayo river (municipalities of Sibundoy, Colon, Santiago, north of Villagarzon) 2. Guamuez Basin (southern Pasto and northern municipality of Orito)	1. Source of the Putumayo River (municipalities Sibundoy, Colon, Santiago, north of Villagarzon) 2. Guamuez Basin (southern Pasto and northern municipality of Orito)
Napo	1. Central part of the Tena Canton 2. Santa Clara, Arajuno Cantons 3. High part of Loreto	1. Southwest Antisana Ecological Reserve (western Canton Archidona) 2. Central part of the Tena Canton 3. Santa Clara, Arajuno Cantons 4. High part of Loreto
Pastaza	1. Upper basin of the Pastaza (cantons Latacunga, Saquisilí, Pujili and Salcedo) 2. Upper and middle parts of Canton Pastaza 3. Canton Huamboya	1. Upperbasin of the Pastaza (cantons Latacunga, Saquisili, Pujili and Salcedo, Ambato and San Pedro de Pelileo, Guano, Riobamba, ColtaGuamote) 2. Upper and middle parts of Canton Pastaza 3. Canton Huamboya
Santiago	1. Southwest Morona canton (in the PN Sangay) 2. Logroño Canton	1. Southwest Morona canton (in the PN Sangay) 2. Logroño Canton
Zamora / Cenepa	1. Watershed Media (Limón Indanza, San Juan Bosco, Gualaquiza, El Pangui, Yantzazaand Centinela del Condor) 2. Middle basin - lower (province of Condorcanqui)	1. Watershed Media (LemonIndanza, San Juan Bosco, Gualaquiza, El Pangui, Yantzazaand Centinela del Condor) 2. Middle basin - lower (province of Condorcanqui)
Marañon	1. National Shrine Tabaconas - Namballe; San Ignacio and Huancabamba province 2. Bagua Province	1. National Shrine Tabaconas - Namballe; San Ignacio and Huancabamba province 2. Bagua Province

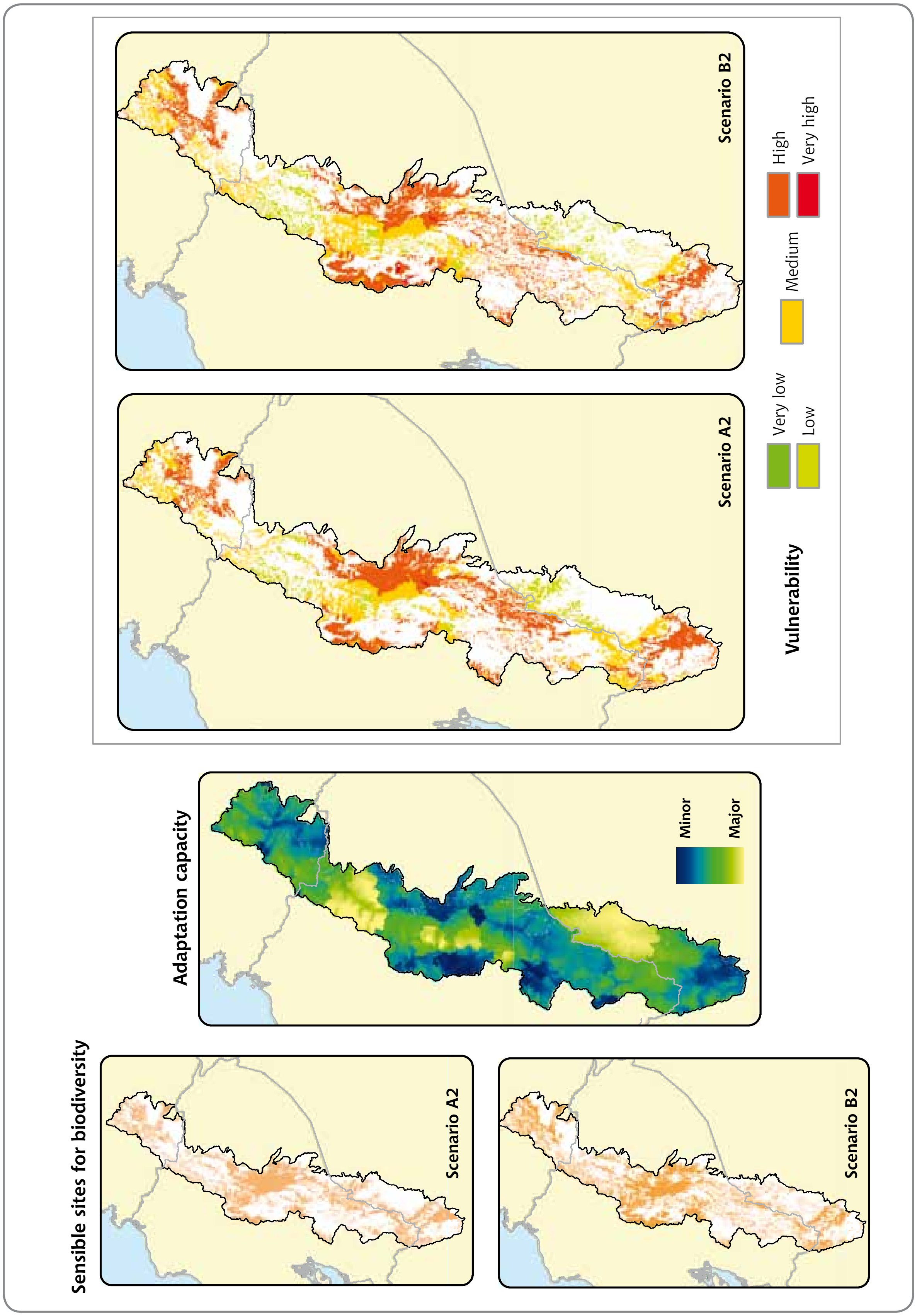

Figure 6. Vulnerability to climate change of the major watersheds of the Eastern Cordillera Real.

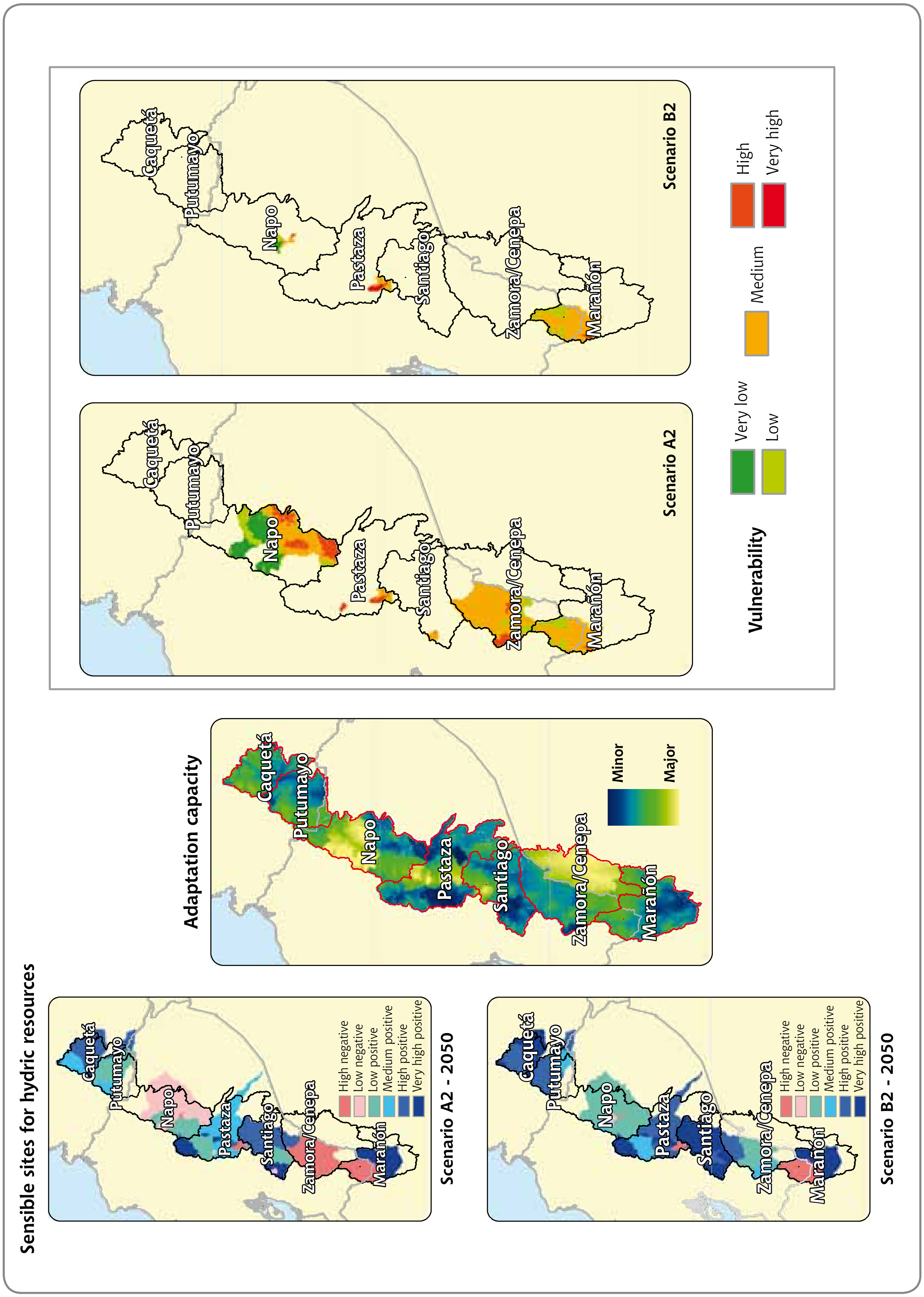

Figure 7. Vulnerable areas for the water sector in the Eastern Cordillera Real.

Chapter

3

Guidelines for a regional strategy

The assessment of vulnerability to climate change is important to respond to future risks. In the case of the Eastern Cordillera Real (ECR) there are serious reasons for concern (see conclusions chart of the analysis).For this reason, and in order to help develop a regional strategy to address at different scales the multiple threats arising from climate change in the ECR, in this section we propose a set of guidelines derived from a combination of exercises and workshops held under the project "A Living Landscape." We hope that the guidelines outlined here will form the basis for a collegiate effort that results in regional integration around the conservation and sustainable development of the ecosystems of the Eastern Cordillera Real, regarding the challenges and threats they face in relation to the global climate change.

Effects of climate change and anthropogenic transformation of ecosystems

The impacts of climate change on the mountain ecosystems of the ECR cannot be interpreted if we do not sufficiently examine their relationships with the effects resulting from human activities. The ecological integrity of mountain ecosystems in the ECR is altered by the change of hydro-meteorological regimes, but these effects are enhanced in many cases by patterns of land use (Fig. 8).

In this model, it is clear that the threats arising from exposure of the landscape units to climate change at a regional scale are also other factors resulting from anthropogenic processes in which multiple stakeholders play a role. The vulnerability of watersheds, within the meaning of IPCC (2008), is then the local expression of the combinatorial of: 1) exposure to climate change in purely biophysical terms (melting glaciers, increased frequency and intensity of rainfall and drought); 2) its associated impacts (massive changes in the distribution of ecosystems and species, increased loss of agricultural crops), 3) the sensitivity resulting from cultural factors and practices (extensive grazing, inadequate and illegal exploitation of timber and non - timber forest products, industrial expansion of forest and agricultural plantations, unsustainable systems of small-scale production and the development of mega infrastructure projects), and 4) sociocultural response and capability that emerge from existing institutional policy frameworks and the level of public awareness about environmental vulnerability.

The relative importance of threats varies between basins and between larger units of landscape within each basin. However, one way to examine them according to their priority at regional level is to assign to each threat ordinal score according to three criteria: extent, severity and urgency. The results of an analysis of this nature (Table 6) identify the expansion of cattle ranching, inappropriate and illegal exploitation of forest products and timber and unsustainable production systems on a small scale as the most urgent threats to be addressed to maintain the resilience of ecosystems in the watersheds to climate change. For this reason, albeit we cannot significantly change the exposure of an ecosystem to climate change and its "natural" sensitivity, we can act on those variables that directly depend on our individual and collective decisions. Production systems, capacity building, public awareness and the development or adjustment of public policies and industry, may have important implications in improving the resilience of economic and social landscapes of the ECR.

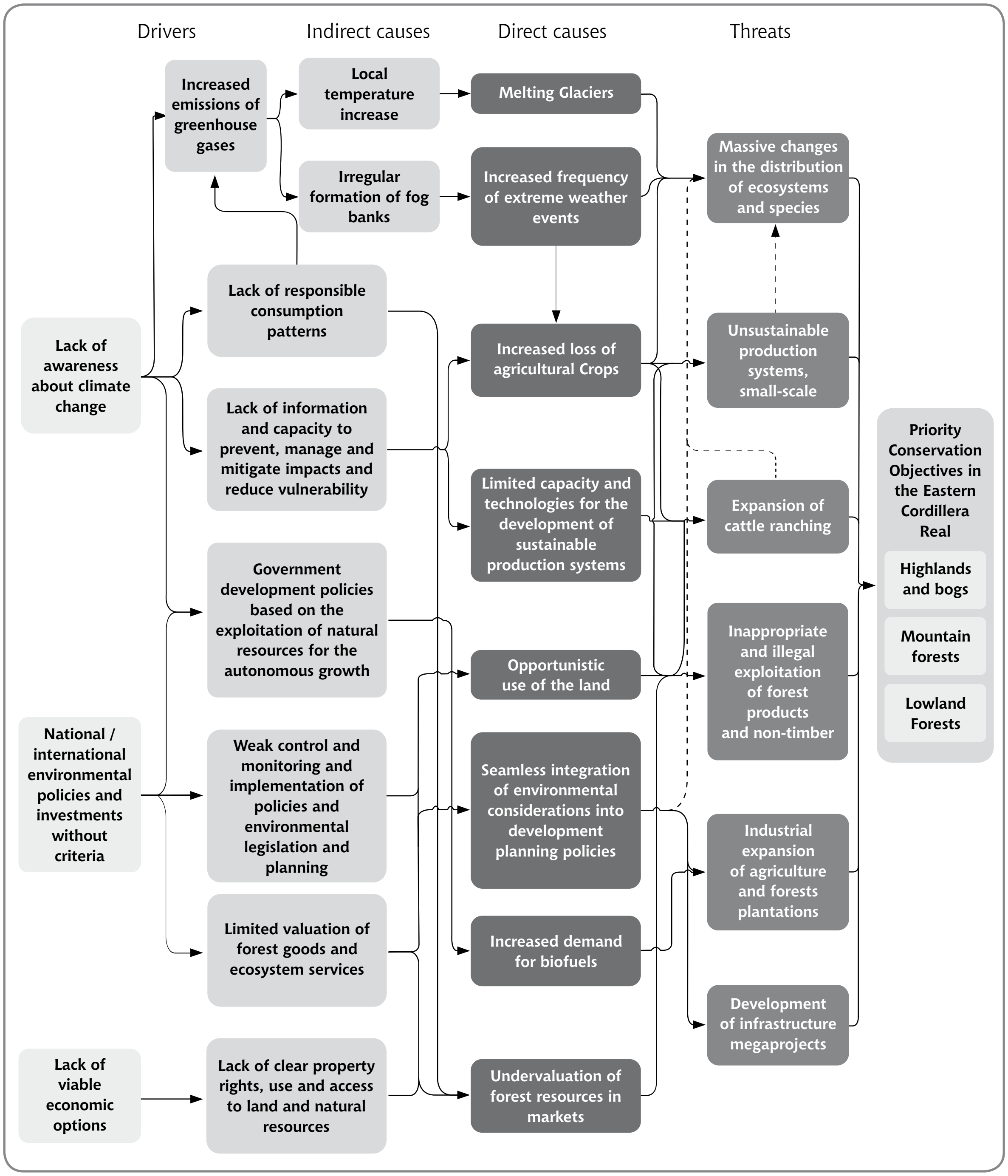

Figure 8. Conceptual model of threats, direct and indirect causes and drivers affecting ecological integrity in major watersheds of the Eastern Cordillera Real.

Possibilities and limitations for adaptation in the ECR

From the emergencies identified in the conceptual model of threats to the maintenance of regional ecological integrity in the ECR (Fig. 8), the regional workshop participants deemed necessary to analyze the possibilities of intervention for the development of adaptation measures around three main lines of work. First, it is necessary ensure access to relevant, timely and clear information aimed at the adaptive management of ecosystems. In this sense there is a fundamental requirement to have effective socialization mechanisms (dissemination, communication, education) which allow at all times to get as many social and institutional stakeholders involved in the development of adaptation measures. A second group of actions are under the theme of public management and coordination, in which the public institutions, along with the economic and non-governmental institutional stakeholders should coordinate their actions in order to optimize the resources needed to develop specific adaptation actions. Finally, the identification of local adaptation actions is a quintessential component of the strategy, since it is necessary to develop community-based actions that have the right perspective "from the inside out." In order to ensure this view, the workshop included the participation of local stakeholders in national exercises in the three countries, who provided recommendations for the national workshops..

Having identified the major thematic lines, participants in the regional workshop conducted an analysis of strengths, weaknesses, opportunities and threats to their development (Table 7). Emphasis was made on all work tables on the importance of taking into account existing institutional developments in the three countries to address the problems of climate change.

Table 6. Prioritization of direct threats to mountain ecosystems of the ECR.

Threat	Extension	Severity	Urgency	Pri-ority
Expansion of cattle ranching	6	6	3	15
Inappropriate and illegal exploitation of timber and non-timber forest products	5	4	5	14
Unsustainable small - scale production systems	4	2	6	12
Massive changes in the distribution of ecosystems and species	3	5	1	9
Industrial expansion and agricultural plantations	2	3	2	7
Development of infrastructure megaprojects	1	1	4	6

Institutional framework

The three countries whose territory makes part of the ECR have made progress in recent years in the development of climate change mitigation and adaptation measures. A study in development led by the International Institute for Sustainable Development (IISD) states that Colombia and Peru are among the most highly advanced countries in developing policies on the issue of adaptation in South America and has clearly recognized the importance of adaptation to climate change as a development issue by engaging the subject in their development plans. Said study also indicates that Ecuador recognizes climate change as an issue in their development plan.

The Ministry of Environment of Peru (Minam) recently completed the Second National Communication on Climate Change (SCNCC) to the UN Framework Convention on Climate Change. This document expresses the intention to develop guidelines for an action plan for adaptation, based on local assessments integrated in several watersheds, vulnerability assessments and adaptation in national priority sectors (agriculture, energy, water and transport) and availability of water resources at national level and basins with glacier inputs. Once completed, these studies will join the National Climate Change Strategy. It is also worth noting that the Bicentennial Plan (current development plan) recognizes the threat of climate change in the context of strategic development issues.

Table 7. SWOT analysis to identify priority elements for adaptation to climate change in the Eastern Cordillera Real.

Subject line	Strengths	Opportunities	Threats	Weaknesses
Information and knowledge	• Available information. • High interest of generating information. • Highly qualified personnel. • Growing awareness of environmental agencies about the importance of communications.	• Growing interest in articulating initiatives. • Existence of environmental laws. • Existence of public channels to disseminate and educate on the subject.	• High degree of uncertainty. • Primacy of economic interests over environmental concerns. • Economic status of communities in the region. • Lack of environmental awareness. • Lack of training of media on the issue of climate change.	• Communicators poorly trained / specialized. • Lack of interaction between those who produce the information - Generators of information and dissemination thereof. • Poor speech dialog. • Lack of coordination between initiatives of the state and civil society. • Lack of resources. • Lack of priority to issues of communication. • Lack of coherence between the messages issued and national policies.

Subject line	Strengths	Opportunities	Threats	Weaknesses
Governance	• There is a regional group with the participation of stakeholders from different levels (ECR process) with defined scope. • Agreement of 14 countries on the importance of the issue of adaptation in the international arena. • CAN's environmental and climate change agenda - political will. • Cultural identity of the region. • Conservation areas and axes / core management in the ECR. • Traditional knowledge associated with the conservation and use of natural resources.	• Existence of project initiatives and conservation processes where you can articulate the theme of climate change. • The issue of climate change is part of the agenda (greater social provision). • Renewal policy US / EU. • Lessons learned from the analysis of baseline vulnerability and adaptation. • Adaptation Fund. • Changes in legislation in favor of development projects.		• Economic crisis, an economic disadvantage. • Economic and political agreements, bilateral, multilateral. • Public Order. • Infrastructure projects. • Major development projects that generate changes in land use. • Changes and flexibility in licensing.
Local adaptation	• Knowledge of the local situation - proposals that arise from the local. • Existing Community Organization. • Presence of ecosystems (remaining). • Existence of good agricultural environmental practices.	• International cooperation with major interest in climate change. • Take advantage of the theme of the day (fashion). • Growing awareness of the problem.	• Lack of knowledge about exactly what is climate change locally. • Local governments weak. • Weak organizational and technical capacity. • Information base is small and of poor quality. • No clarity on the causes and effects of climate change.	• Development models - mega works. • Activity extraction - mining, others. • Loss, cultural erosion. • Economic resources can generate paternalism and dependency. • Changes make more favorable geographic areas for agriculture.

In the case of Ecuador, the Development Plan (*Plan Nacional para el Buen Vivir* 2009-2013) refers to the adaptation and mitigation to climate change as one of the seven policies in the objective related to ensuring the rights of nature and promoting a healthy and sustainable environment. According to the IISD document under construction, the policy includes the generation of adaptive programs, with particular emphasis on ecosystems, emergency prevention programs for the infrastructure sector, adaptation initiatives related to energy and food security, vulnerability assessments and impacts, and technology transfer.

Colombia produced the first communication to the United Nations Framework Convention on Climate Change in 2001, and thereafter Colombia established the guidelines for the Climate Change Policy (2002) and created the Colombia Office for Climate Change Mitigation (2002). Among the actions aimed at developing the National Policy on Climate Change, Colombia is currently developing the INAP project, cofinanced by the Global Environment Fund, which aims to define and implement pilot adaptation measures and policy options to prepare the country to resolve in advance the negative effects of climate change.

On the other hand, the country presented in 2010 the Second Communication to the United Nations, wherein Colombia identifies different sectors vulnerable to climate change, including water, infrastructure, energy, agriculture and biodiversity. This is acknowledged in the National Development Plan 2010-2014 which, according to the IISD study, mentions adaptation several times as a crosscutting issue, states that the sectors should develop their own plans to adapt to change climate and territories should receive central government support to develop regional strategies. Colombia is currently awaiting approval of the policy document (CONPES) on Climate Change,which seeks to develop a corporate strategy for the articulation of policies and actions on climate change.

Guidelines for a regional strategy for climate change adaptation in the ECR (Colombia, Ecuador and Peru)[8]

From the action lines identified and the SWOT analysis, the regional workshop participants reached agreement on the vision that the regional strategy should have. In order to establish this view the approach was considered important in order to identify a horizon, a subject of action, an object that reflects the ecological complexity and dependency of local communities in the resource base and procedural elements that guide the actions of the strategy. According to these principles, the consensus view was:

By 2030, communities and institutions maintain and restore the integrity of the ecosystems, the provision of services and the sustainability of the production systems

8. Adapted from: Barrera, M.X., E. Fiallo-Pantziou y L.G. Naranjo. 2010. Adaptación al cambio climático en la Cordillera Real Oriental: Lineamientos para una estrategia regional. Pp 83 - 94. En: Naranjo, L.G. (Ed). Cambio climático en un paisaje vivo: vulnerabilidad y adaptación en la Cordillera Real Oriental de Colombia, Ecuador y Perú. Cali. Fundación Natura - WWF *based on mechanisms associated with sound environmental governance for adaptation to climate change and the proper formulation and implementation of state policies.*

Having defined the vision of the strategy, the objectives for each course of action were developed and the goals and expected results were identified to account for these targets (Table 8).

Table 8. Goals, objectives and expected results of a regional strategy for adaptation to climate change in the Eastern Cordillera Real

Action Line 1: Governance

Objective

Strengthen regional policy framework considerations of vulnerability and adaptation of climate change with participation and influence of stakeholders in the ECR.

Goals	Achieved
By 2013 the policies, plans, programs and projects are formulated and implemented with participation of a representative percentage of social and institutional stakeholders of the ECR.	Public policies in the three countries have been articulated based on the component of vulnerability and adaptation.
	Regional plan for the implementation of CC adaptation strategy among the three countries with the action plan articulated in the CAN.
	Joint position and cohesive of the three countries on the issue of climate change adaptation and impacts strengthens international negotiations.
	ECR stakeholders strengthened for the participation and influence in the formulation and implementation of public policies.
By 2020, there will be a policy framework with considerations of vulnerability and resilience, articulated for the region.	Planning processes in the three countries to incorporate local and regional component of vulnerability and adaptation.

Action Line 2: Local Adaptation

Objective

Develop and enhance local capabilities and productive potential of communities and institutions that help maintain and / or restore ecosystem resilience to climate.

Goals	Achieved
By 2013, plans, programs and infrastructure and extractive projects have included determinants of vulnerability and adaptation to CC.	The PPP are formulated in a participatory local development incorporating aspects of vulnerability and adaptation to CC.
By 2013, pilot programs on compensation mechanisms for environmental goods and services will have been implemented at least three strategic areas.	Compensation mechanisms for environmental goods and services are generated and implemented in priority areas.
For 2013, we have adequate production systems in three strategic areas through conservation practices and soil management to minimize the risks associated with CC.	Local populations have sustainable productive alternatives that minimize the risks associated with climate change.
By 2020, local systems are in operation in conservation areas.	Local systems of conservation areas designed and linked to different levels of management and helping to preserve local ecological functionality.

▶

Action Line 3: Information and Knowledge

Objective

Strengthen the management capacity and socialization of information to promote and increase public participation influencing decisions-making.

<table>
<tr><th>Goals</th><th>Achieved</th></tr>
<tr><td>By 2013, 15% of communities in the ECR partake in and influence the political decision-making for adaptation to climate change.</td><td rowspan="6">Information available, on a timely and free – access base.

Information translated into a language suitable for each audience.

Communities sensitized about the need to adapt to CC.

Information is disseminated in a timely manner to the media and civil society.

Decision makers are aware and engaged.</td></tr>
<tr><td>By 2013, coverage of the issue of climate change in the media will increase by 25%.</td></tr>
<tr><td>2016, 45% of ECR communities partake in and influence the political decision-making to adapt to climate change.</td></tr>
<tr><td>By 2016, coverage of the issue of climate change in the media will increase by 35%.</td></tr>
<tr><td>2020, 60% of communities in the ECR partake in and influence the political decision-making to adapt to climate change.</td></tr>
<tr><td>By 2020, coverage of the issue of climate change in the media will increase by 45%.</td></tr>
</table>

Operational recommendations for the implementation of the strategy

The implementation of an adaptation strategy for such as large and complex region as the ECR undoubtedly requires the participation and commitment of many institutional stakeholders and a broad base of civil society. Recognizing the magnitude of this challenge, some recommendations were made during the regional workshop held in Quito in April 2009.

At the regional level it was recommended to seek articulation of these guidelines with the joint action plans of CAN (Community of Andean Nations), so as to facilitate the integration of the work that governmental bodies of the three countries are leading. This requires the management by the ministries and research institutions concerned, with the support of organizations which have been working on this process (Fundación Natura and WWF) and the participation of CAN.

At the national level, the coordinating committee of the project "A Living Landscape" must take responsibility for making recommendations for developing the adaptation strategy to climate change at the respective government bodies of the three countries for their consideration at the policy formulation process.

Finally, at the local level, it is important that the actions identified in these processes provide feedback to the strategic guidelines and action plans which are currently underway in the various basins of the ECR. In this sense, WWF and Fundación Natura, as well as their network of institutional partners, must take responsibility to seek continuity in the development of the specific actions identified.

Finally, the workshop suggested a regional operational structure to implement the strategy, formed by the coordinating committee of the project "A Living Landscape" (Fundación Natura and WWF offices in Colombia and Peru), and expanded to incorporate the Ministries of Environment of the three countries, who will also have outside consultants. The three representative institutions in each country will work on the three action lines identified (*i. e.* Public Management, information and knowledge and local adaptation) both locally and regionally.

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This document is a translated summary of the original publication resulting from the initiative *Cambio climático en un paisaje vivo: Vulnerabilidad y adaptación en la Cordillera Real Oriental de Colombia, Ecuador y Perú (WWF y Fundación Natura 2010).* We have focused primarily on presenting the methodological aspects of the vulnerability analysis, providing information on Eastern Cordillera Real (ECR) to illustrate how we applied the Turner II *et al*. (2003) three-pronged framework for understanding vulnerability of a system to environmental change. The results of the combined vulnerability analyses (biological, hydrological and socioeconomic) for the ECR demonstrate the need for actions oriented at maintaining the continued provision of ecosystem services as well as the biological and cultural riches of the region.

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