ASSESSING MONETARY VALUATION METHODOLOGIES FOR ESTIMATING THE IMPACTS OF CLIMATE CHANGE IN THE LAGUNA DE ROCHA (URUGUAY)

by

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Table of Contents

List of Tables

List of Figures

Abstract

The motivation for this study arose from the dual observation that there are very few estimates of the local costs of climate change in developing countries and that the few studies that do exist rarely take into account the non-market value of ecosystem services. Using a case study of a coastal lagoon ecosystem in Uruguay, I explore practical reasons for why this might be the case. Informational difficulties related to identifying local climate trends and the identification of ecosystem services as well as the relevance and feasibility of monetary valuation methodologies are discussed using specific examples. Three valuation methodologies are implemented to estimate the monetary values of climate change impacts on specific ecosystem services. The results suggest that climate change is affecting the economic value of the coastal lagoon ecosystem. Implications for local management and lessons learned from the case study are discussed.

List of Abbreviations Used

ALZ	Active Littoral Zone
CDM	Clean Development Mechanism
CERs	Certified Emissions Reduction
CO_2	Carbon dioxide
CV	Contingent Valuation
DINAMA	Direccion Nacional de Medio Ambiente (*National Environment Authority)*
DNM	Direccion Nacional de Meteorologia (*National Meteorology Authority)*
ENSO	El Nino-Southern Oscillation
GEF	Global Environment Facility
IBA	Important Bird Area
IDRC	International Development Research Centre
IPCC	Intergovernmental Panel on Climate Change
LLGHGs	Long-lived Greenhouse Gase
LR	Laguna de Rocha
LRPA	Laguna de Rocha Protected Area
N_20	Nitrous oxide
MVOTMA	Ministry of Housing, Territorial Regulation and Environment
NH_4	Methane
PF	Production Function
SACZ	South Atlantic Convergence Zone
SALLJ	South American Low-level Jet
SAMS	South American Monsoon System
SESA	South-east South America
SST	Sea Surface Temperature
TCM	Travel Cost Method
TEEB	The Economics of Ecosystems and Biodiversity
TEV	Total Economic Value
UdelaR	Universidad de la Republica (*University of the Republic*)
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
WHSRN	Western Hemisphere Shorebird Reserve Network
WMO	World Meteorological Organization
WTP/WTA	Willing-to-Pay/Willing-to-Accept

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CHAPTER 1: INTRODUCTION

There is unequivocal evidence that greenhouse gas emissions from human activities are altering the global climate (Christensen et al., 2007). Given the overwhelming evidence that the increasing greenhouse effect is due to emissions from human production and consumption patterns, climate change has been recognized as “the greatest and widest-ranging market failure ever seen” (Stern, 2007). Considerable uncertainty is attached to any predictions of climate change impacts due to incomplete understanding of the many inter-related variables in natural and social systems including climate forcing agents, feedback mechanisms, ecosystems and socio-economic development scenarios (Nakicenovic et al., 2000). There have been many calls from policy-makers and relevant stakeholders for estimates of the local impacts of climate change, especially in monetary terms (Agrawala and Fankhauser, 2008; Parry et al., 2009; World Bank, 2010).

Many ecosystems that people rely upon for their wellbeing are being impacted by climate change in Latin America (Barros et al., 2008). Coastal zones are particularly vulnerable due to their high population densities and exposure to sea-level rise, increasing storminess and other hazards (Adger et al., 2005). In particular, South America has experienced a dramatic shift in precipitation patterns over the last forty years, with annual decreases of up to 50% observed west of the Andes while increases of almost 30% have been observed to the East in southern Brazil, Uruguay and Argentina (Barros, 2004).

The general objective of this report is to test the feasibility and relevance of monetary valuation methodologies for estimating the local costs of climate change impacts in the 22,000 ha Laguna de Rocha Protected Area (LRPA) on the Atlantic coast of Uruguay. This issue was chosen based on consultations with local stakeholders that identified a perceived gap in knowledge that could be at least partially filled during my one-year research award in 2011 based at the Latin America and Caribbean Regional Office of the International Development Research Centre (IDRC) in Montevideo, Uruguay.

In order to achieve the general objective stated above, a number of successive research questions arose. First and foremost, is the local climate changing in Rocha? Next, what ecosystem services are physically provided by the LRPA and how, if at all, are they vulnerable to a changing climate? From an economic perspective, what valuation methodologies are relevant for estimating the local costs and benefits of climate impacts on LRPA ecosystem services? Finally, which methodologies can be feasibly implemented and what are the data needs? The hypothesis is that understanding the site-specific challenges for estimating the market and non-market impacts of climate change can help inform the design of climate-resilient strategies in the LRPA management plan. Furthermore, using the example of a developing country protected area, it is hoped that the methodology and information in this study will inform future research on producing credible estimates of the local value of climate change impacts in developing countries.

The thesis is organized as follows. Chapter 2 begins with a discussion of the global climate system in relation to the regional climate of South-east South America and then focuses on identifying long-term trends in temperature, precipitation, sea levels and winds for Rocha, Uruguay. Chapter 3 provides an ecological characterization of the coastal lagoon area and uses an ecosystem assessment framework to select ecosystem services provided by the LRPA that are vulnerable to observed climate trends. Chapter 4 moves away from the biophysical impacts of climate change and explores what those impacts are worth to people through an analysis of the economic notion of value, its limitations and a conceptual framework for the monetary valuation of ecosystems. Chapter 5 analyses the various approaches and methodologies used to place a monetary value on different ecosystem services and maps the specific relevance and feasibility of each for the ecosystem services identified in the LRPA. Chapter 6 demonstrates three of the most relevant and/or feasible methodologies to estimate monetary values for: i) precipitation changes on shrimp production; ii) carbon sequestration services; and iii) climate impacts on habitat maintenance and cultural services. Results and methodologies' strengths/limitations are discussed critically throughout the text. Chapter 7 concludes.

It is hoped that the information in this study will be useful to LRPA managers and other Uruguayan stakeholders as well as members of the international community interested in the identification and valuation of local climate change impacts on ecosystems and people.

CHAPTER 2: OBSERVED CLIMATE CHANGES IN ROCHA (URUGUAY)

2.0 Introduction

Before attempting any monetary estimates of climate change impacts, the first step is to explore the hypothesis that climate change is actually having a physical impact on the Laguna de Rocha Protected Area (LRPA). In particular, how do changes in the local climate impact the ecosystem services provided by the LRPA? This chapter addresses the first part of the above question by exploring the dynamics of the global climate system and effects of past and current global greenhouse gas (GHG) emissions in order to identify changes to the regional climate system of the south-East Atlantic, with a focus on the Rocha Department[1] (Uruguay). The following chapters will build from these observed climate trends to explore their impacts on the lagoon ecosystem from ecological and economic perspectives.

2.1 What Is the Global Climate System and How Can it Change?

In order to understand the specific impacts of climate change on the 22,000 ha Laguna de Rocha Protected Area, it is worthwhile to begin with a brief description of the climate system and, more specifically, our understanding of the ways that that system can be changed. The following sub-sections provide a summary of the peer-reviewed climate science literature using the resources of the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report (2007) whenever possible.

Climate can be defined neatly as 'average weather' or, more formally, as the "statistical description in terms of the mean and variability of relevant quantities [often surface temperature, precipitation and wind] over a period of time ranging from months to thousands or millions of years" (IPCC, 2007). The international standard for climate data from the World Meteorological Organization (WMO) is for thirty year averages. The use of statistics to identify long-term trends gives climate prediction more certainty than predicting individual weather events in the same way that we know, on average and given 'enough' tosses, a coin will land heads-up 50% of the time. A quote from Heinlein (1973) captures it well: "climate is what you expect [and] weather is what you get". As such, climate can be seen as a statistical description of the state resulting from the complex interactions between the five major components that determine the global

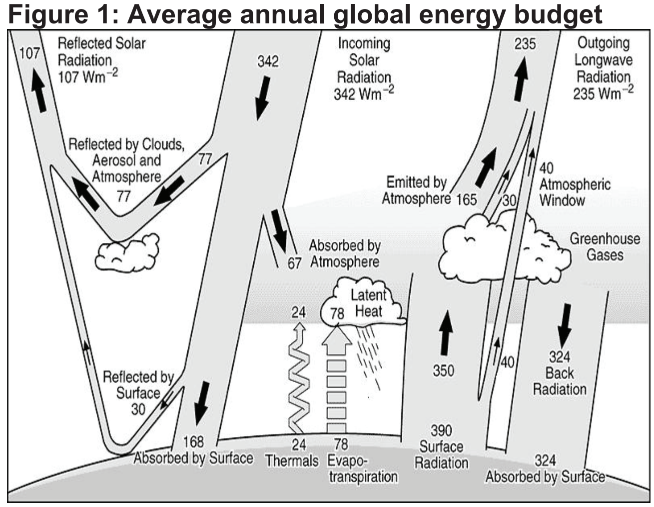
[1] An administrative unit similar to a Canadian province

climate system: i) atmosphere; ii) oceans and other water bodies; iii) snow and ice; iv) land surface; and v) living things (Forster et al., 2007).

The Earth's climate system is powered by solar radiation and evolves according to its own internal processes as well as – and this is the particularly important bit for our purposes – external factors of natural *and/or* anthropogenic origin that affect climate, commonly referred to as 'forcings' (Le Treut et al., 2007).

Figure 1 depicts the Earth's annual and global mean energy balance derived from the Sun's rays, around 30% of which are reflected back into Space by clouds, aerosols and light-coloured parts of the Earth's surface (known as the albedo effect). The remaining two-thirds are absorbed by the surface and atmosphere and eventually emitted back into Space as long-wave (thermal) radiation (Kiehl and Trenberth, 1997).

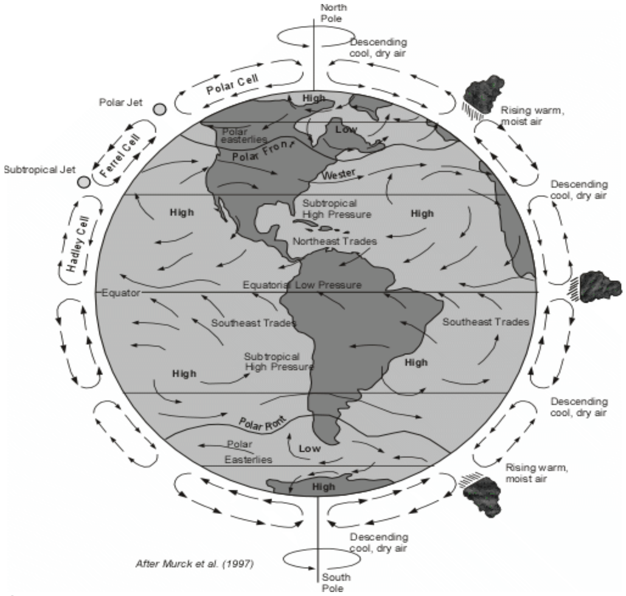
Figure 1: Average annual global energy budget



A stylized schematic of the Earth's annual global average energy budget. Units are in Watts per square meter per second (Wm^{-2}) **Source:** Kiehl and Trenberth (1997)

In the interim, the presence of greenhouse gases in the atmosphere – known as the natural greenhouse effect – traps the majority of the radiation emitted by the planet's surface making it habitable for life as we know it at a global average of 14°C instead of the chilly-19°C surface temperature needed to thermodynamically balance the incoming solar radiation (Le Treut et al., 2007).

Figure 2: Global Atmospheric Circulation Patterns



Stylized global atmospheric circulation patterns showing three major convection cells and their zones of low pressure (rising air) and high pressure (descending air) that, due to the Coriolis Effect, create cyclonic and anticyclonic winds, respectively. **Source:** Nelson (2010)

Atmospheric circulation patterns (including storms) are driven mainly by the energy used to evaporate water from the surface that is later released when the water vapour is condensed to form clouds – known as the latent heat flux (IPCC, 2007). In turn, oceanic circulation is tightly coupled with atmospheric circulation patterns driven by surface winds, temperatures and salinity (from evaporation and precipitation). Finally, Figure 1 presents global averages; however, it is well known that the Earth is a sphere and that the tropics absorb more solar radiation than the poles.

A crucial element of the dynamics of the climate system is to understand how energy is transported northwards and southwards from the net-surplus tropics to the net-deficit poles (Baines, 2006) (Figure 2). Figure 2 presents a stylized depiction of global atmospheric circulation patterns characterized by three atmospheric convection cells – Hadley, Ferrel and Polar, respectively– that carry warm (low pressure) air that rises from the tropical surface into the upper atmosphere until cooling and descending (high pressure) in the upper latitudes (Nelson, 2010). Winds blow from zones of high pressure to zones of low pressure but the rotation of the planet causes the air to deflect to the right in the northern hemisphere and to the left in the southern hemisphere – known as the Coriolis Effect (Thurman and Trujillo, 2002). As a result, winds circulate around low pressure centers (cyclonic winds) and spiral outward from high pressure centers (anticyclonic winds). It must be noted that Figure 2 does not capture the meandering nature of the jet-streams – narrow bands of high-velocity winds between the cells in the upper atmosphere – that cause the cold and warm fronts of these low and high pressure systems to migrate north-south and cause much of the familiar variability in the weather (Nelson, 2010).

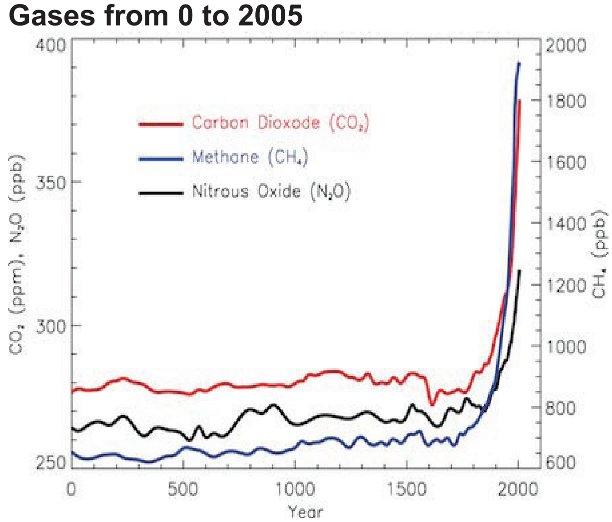
2.1.1 How Can the Climate System Change?

Keeping in mind that the climate system is driven by solar energy, scientists have identified three factors that can change the incoming and outgoing energy (or radiative) balance of the Earth and affect climate directly or indirectly through various feedback mechanisms (Le Treut et al., 2007). Firstly, *astronomical changes* to incoming radiation can be through changes in: i) the Earth's orbit around the Sun; and/or ii) the energy output from the Sun itself. Secondly, *reflective changes* to the fraction of incoming radiation deflected by the planet's albedo effect (e.g. changes in cloud cover, aerosols and light-coloured land surfaces) also change the radiative balance. Finally, *atmospheric changes* alter the outgoing long-wave radiation from Earth back towards Space through changes in atmospheric greenhouse gas abundance. These three types of external forcings on the radiative balance – or radiative forcing agents – can have either natural (e.g. solar irradiance, volcanic eruptions) or anthropogenic causes (e.g. GHG emissions) (Nelson, 2010). By analyzing all of the known natural and anthropogenic radiative forcing agents, it is now *extremely likely* – greater than 95% confidence – that humans have contributed substantially to both atmospheric and reflective changes that have produced a net warming of the global climate since 1750 (Forster et al., 2007).

2.1.2 Observed Climate Warming Caused by Greenhouse Gas Emissions and Other Climate Forcing Agents

The long-lived greenhouse gases (LLGHGs) refer to carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). CO_2 emissions from the burning of fossil fuels and removal of forests are the most important, and best-understood, anthropogenic forcing agent on the global climate (ibid). From 10,000 years ago until 1750, CO_2 abundance in the atmosphere remained relatively stable between 260 and 285 ppm (Indermühle et al., 1999).

Figure 3 – Concentrations of Greenhouse Gases from 0 to 2005

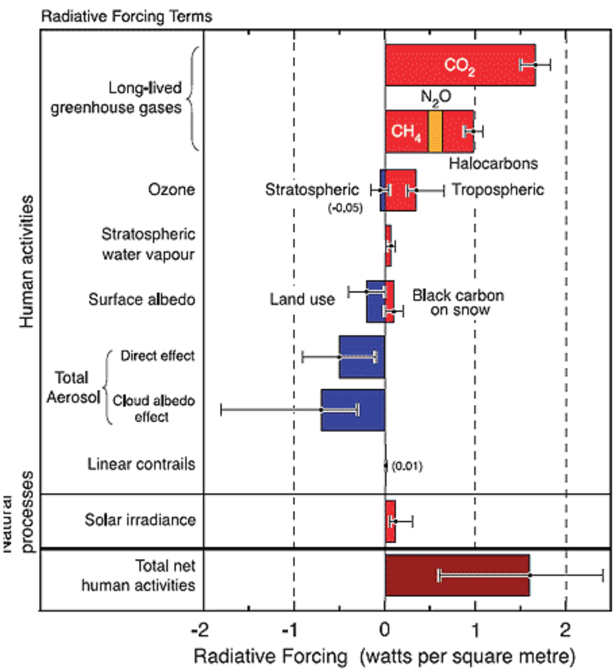


Source: Forster et al. (2007)

Scientists have now extended the CO_2 record back more than half a million years and found that its abundance has never exceeded 300 ppm over that whole period

(Siegenthaler et al., 2005). Since the industrial era began, CO_2 abundance has been increasing exponentially from 280 ppm to current levels around 390 ppm (Le Treut et al., 2007; NOAA-ESRL, 2011).This represents a 36% increase in CO_2 abundance over the last two hundred and sixty years compared to the relatively stable previous 10,000. Roughly 74% of this increase in CO_2 abundance has occurred in the last fifty years. The abundance of methane and nitrous oxide has also increased dramatically since the 18th century relative to records obtained from air bubbles in ice cores spanning more than half a million years (Le Treut et al, 2007) (Figure 3).

Figure 4 – Radiative forcing of climate between 1750 and 2005



Human activities have caused significant changes in LLGHGs, ozone, water vapour, surface albedo, aerosols and contrails between 1750 and 2005. The only increase in natural forcings with any significance occurred in solar irradiance. Positive forcings lead to climate warming while negative forcings lead to cooling. The thin black line attached to each coloured bar represents the range of uncertainty for the respective value. **Source:** Forster et al. (2007).

While the largest known cause of climate change is due to the release of CO_2 into the atmosphere from burning fossil fuels, Forster et al. (2007) also analyze the radiative forcing impact of a number of other atmospheric compounds including halocarbons, ozone, water vapour, aerosols (small particles) and linear contrails from aircraft. It must be noted that some human activities cause a cooling effect on the climate system; however the total *net* impact of human activities from 1750 to 2005 has been a warming effect (Figure 4). A great deal of research is devoted to understanding the complex feedback mechanisms that are triggered by the changes observed and summarized in Figures 3 and 4.

For example, Le Treut et al. (2007) describe the 'snow/ice-albedo' amplification – or positive feedback loop – of warming caused by increasing greenhouse gas emissions. Essentially, higher temperatures from more GHGs cause the melting of snow- and ice-covered surfaces thus exposing more dark-coloured land or water surfaces which increase the fraction of incoming radiation absorbed by the planet and cause temperatures to increase further, leading to more melting, and so on. Scientists have observed that Arctic sea-ice is particularly vulnerable to the snow/ice-albedo feedback (Curry et al. 1995). In effect, it is well-known that different regions' climates respond differently to rising average global temperatures and it is far beyond the scope of this paper to attempt to describe them all. Rather, the following sections focus only on the regional climate and observed changes in the South-eastern South America region in order to analyze their potential physical and biological impacts in the Laguna de Rocha Protected Area.

2.2 What are the Regional and Local Trends in Climate for South-east South America and Rocha (Uruguay)?

Regional variations in climate are still not fully understood and are sometimes counter-intuitive so climate scientists attempt to understand by observing circulation changes in the global climate system's *preferred* patterns of variability and how these interact at different time scales (from diurnal to millennial) and over widely separated parts of the world (Trenberth et al., 2007). The essence of these 'teleconnections' between regional climate variations around the globe is captured by the now-famous question: "Does the flap of a butterfly's wings in Brazil cause a tornado in Texas?" (Lorenz, 1972 cited in Hillborn, 2004).

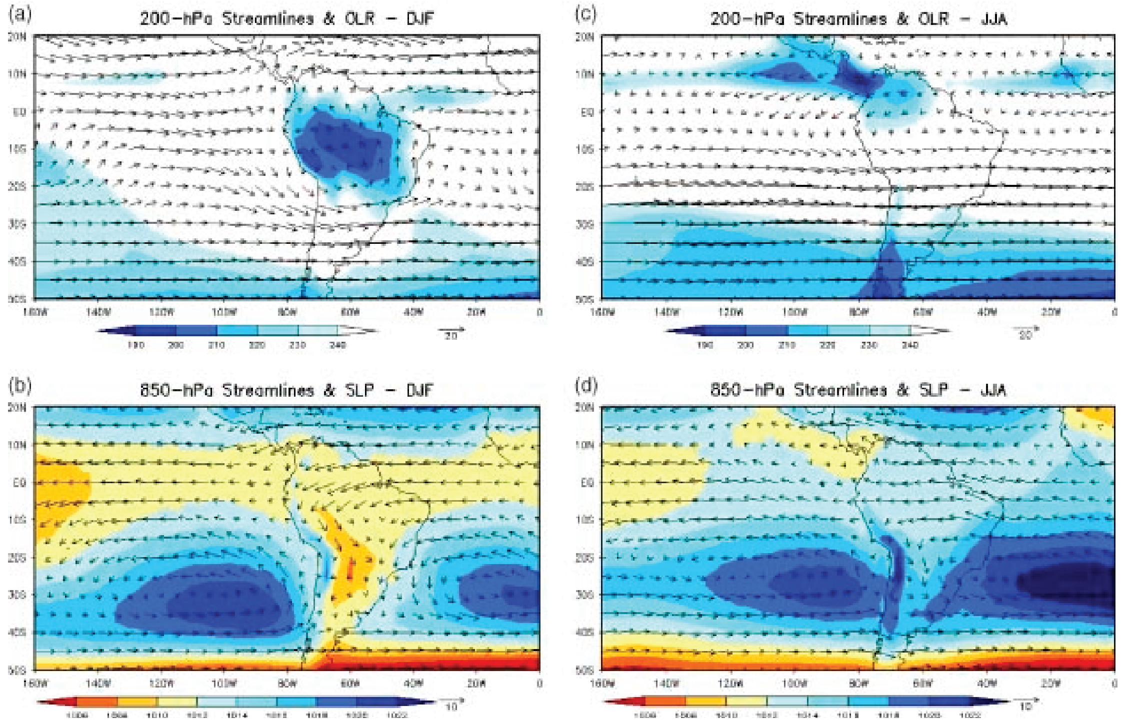
The climate in South-east South America (SESA) described briefly below was compiled from the peer-reviewed literature and focuses on the sub-tropical continental landmass located roughly between 25°S and 45°S bordered by the Andes to the West and the southern Atlantic Ocean to the East. In particular, attention is given to identifying the observed climatic trends in Rocha, Uruguay. National publications were also consulted and discussions were held with regional climate experts (one of whom is an IPCC lead author and Nobel Laureate). The description is not exhaustive and merely intends to provide a snapshot of the observed climatic trends in the region in order to discuss their relevance to the Laguna de Rocha Protected Area. Circulation patterns, sea levels, temperature and precipitation are described in the context of the South American Monsoon System (SAMS) and their changes discussed in turn.

2.2.1 The South American Monsoon System (SAMS): Structure and Dynamics

A monsoon refers to the seasonal reversal of surface winds and associated precipitation in the tropical and sub-tropical regions caused by heat differences between a continental landmass and the adjacent ocean (IPCC, 2007). In the Americas, the northern and southern monsoon systems can be viewed as the two extremes of the same seasonal cycle of convection – locally-induced vertical motion of air usually caused by near-surface warming in the atmosphere (e.g. arrival of Spring in each hemisphere) – characterized by continental precipitation during each hemisphere's summer months (Vera et al., 2006; IPCC, 2007).The SAMS affects most of the South American climate and, due to the importance of monsoon rains for human wellbeing, especially agriculture and hydroelectricity generation, its life cycle and variability has been the focus of considerable research and synthesis (Nogués-Paegle et al., 2002; Vera et al., 2006; Marengo et al., 2010a and references therein).

Figure 5 presents the average atmospheric wind and pressure structure of South America (1979-2008) during austral summer (December-February, or DJF) and winter (June-August, or JJA) at upper- (Figure 5A, C) and lower- (B, D) levels of the troposphere. The main upper-level components are the formation of the 'Bolivian High' and accompanying 'Nordeste low' during the wet summer months over Bolivia and northeast Brazil, respectively (Lenters and Cook, 1997) (Figure 5A). Important low-level features comprise: i) sub-tropical high pressure systems and anticyclonic circulation over both Pacific and Atlantic oceans; ii) the barrier effect of the Andes mountain range; iii) the Chaco thermal low over northern Argentina; iv) the northwesterly South American Low-Level Jet (SALLJ) present throughout the year extending from the Southwest Amazon to Southeast South America; and iv) the summer establishment of the South Atlantic Convergence Zone (SACZ) – an elongated convective band of precipitation originating as a result of the deep convection in the Amazon and extending towards south-eastern Brazil and into the sub-tropical Atlantic (Figure 5B, D) (Vera et al., 2006; Marengo et al., 2010a). The onset, maturity and subsequent decay of deep convection in the Amazon and accompanying establishment of the SACZ are the main components of the SAMS (Carvalho et al., 2004). That being said, observations show that the system demonstrates substantial variability on multiple time scales (diurnal, intra-annual, inter-annual, decadal) due to interactions between the local climatic components listed above as well as effects of global phenomena (e.g. El Niño-Southern Oscillation (ENSO), increasing GHG emissions). As the primary focus of this section is to identify impacts of climate change in South-east South America, the focus will be given to inter-annual and longer-term climate variability as pertains to that region.

Figure 5 – Average (1979-2008) South American atmospheric structure during austral summer (DJF) and winter (JJA) at upper- (200 hPa) and lower- (850 hPa) levels



The South American Monsoon System (SAMS) is characterized by the establishment of deep convection over the Amazon and accompanying precipitation during austral summer (DJF) over much of the tropical and sub-tropical land east of the Andes (A, B). An important component includes the formation of a northwesterly convective band – the South Atlantic Convergence Zone (SACZ) – that generally extends from the southwest Amazon into the south-east Atlantic (B). The convection retreats back towards the northwest as the cold front migrates northwards during austral winter (JJA) (C, D). The figure presents averages over 1979-2008 and units are in Watts per square meter (Wm^{-2}) for outgoing longwave radiation (OLR) and hPa for sea level pressure (SLP). **Source:** Marengo et al. (2010a)

2.2.2 Past and Current Climate Change in South-east South America (Focusing on Rocha, Uruguay)

Figure 6 – Sample of meteorological stations in South America

Rocha station on the Atlantic coast of Uruguay in blue.
Source: Adapted from Vincent et al. (2005)

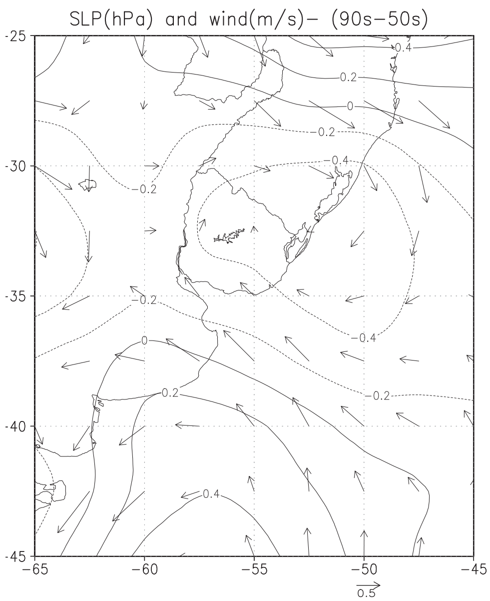
Relative to the rest of South America, the Southeastern region is comparatively rich in climate data leading to numerous studies that have explored climate variability over multiple time scales (Figure 6). In Uruguay, the Rocha meteorological station (34.48°S, 54.30°W) is one of 17 stations currently administered by the *Dirección Nacional de Meteorología* (DNM, National Meteorology Authority). The data collected at this station since operations began ca. 1950 have been used by national and international researchers in conjunction with thousands of other stations in order to produce knowledge that has, among other things, informed the state-of-the-art in climate observations as reported by the IPCC.

That being said, significant gaps remain in the regional climate observation network that create challenges identifying trends within past and current climate variability and change, but the best-known impacts are related to circulation patterns, temperature, precipitation and sea-level rise (Magrin et al., 2007; Marengo et al., 2010b).

<u>Observed changes in sea level pressure and circulation</u>

Over the past sixty years, climatologists have observed a southward displacement of the mean sea level pressure associated with the western border of the South Atlantic High (shown in Figure 5C and D) (Barros et al., 2005). Exploring the proposed *causes* of the southward shift of the South Atlantic anticyclone are beyond the scope of this report besides noting that GHG emissions could be a forcing on the many interactions between the factors mentioned in Section 2.1[2]. By taking the difference between decadal averages in 1951-1960 and 1991-2000, Barros et al. (2005) show that the southward displacement of the pressure field has increased (reduced) the eastern (western) components of the average surface-level winds between 33°S and 40°S on the Atlantic coast of South America (Figure 7).

Figure 7 – Difference between average yearly sea level pressure and wind between 1951-1960 and 1991-2000



Observed net increase in eastern component of low-level winds in 1991-2000 compared to 1951-60 between 33°S and 40°S. Circulation data are derived from NCEP reanalyses. **Source:** Barros et al. (2005)

A 1.2° shift southward of the maximum pressure along the Southeast South American coast has been observed since the early 1970s (significant at the 95% level) that coincides with observed positive trends in precipitation and temperatures discussed below. Barros et al. (2005) perform a principal component analysis to model the seasonal circulation patterns for both summer and winter, finding that the summer circulation pattern of more easterly winds has grown at the expense of the winter pattern during this period (see Figure 5B, D).

For most of southern Uruguay, a decrease in observed atmospheric sea level pressure has been observed between 1961 and 2008 (-0.5 hPa), however the trend is weakest in Rocha (Bidegain et al., 2009). Observed changes on winds, sea-levels, temperature and precipitation in Rocha (Uruguay) are summarized below.

Observed changes in prevailing winds

Two major changes to the prevailing surface winds have been observed in southern Uruguay during the second half of the 20th century. The first is a decrease in average

[2]See Marengo et al. (2010a) for a recent review of literature concerning the South American climate system

monthly wind speeds between 1961 and 2008 from three separate coastal stations, especially since the beginning of the 1990's (Bidegain et al., 2009) (Figure 8). The second relates to the changes in sea level pressure mentioned in the previous section that have resulted in an increase of winds with an easterly influence and a decrease in northerly winds (Verocai, 2009 cit. Nagy, 2011) (Figure 9). It must be noted that the location of the Rocha meteorological station is not conducive to measuring winds reliably so wind trends must be inferred from surrounding stations[3].

Figure 8 – Average monthly wind speed in southern Uruguay (1961-2008)

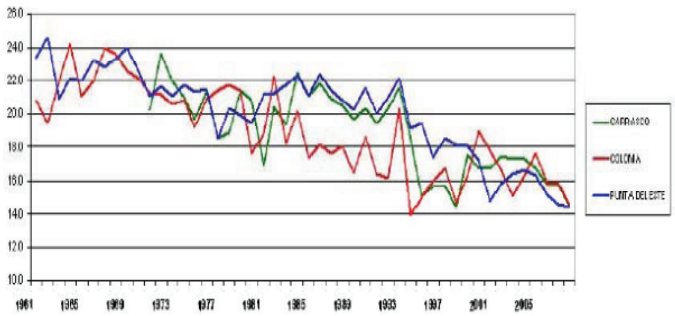
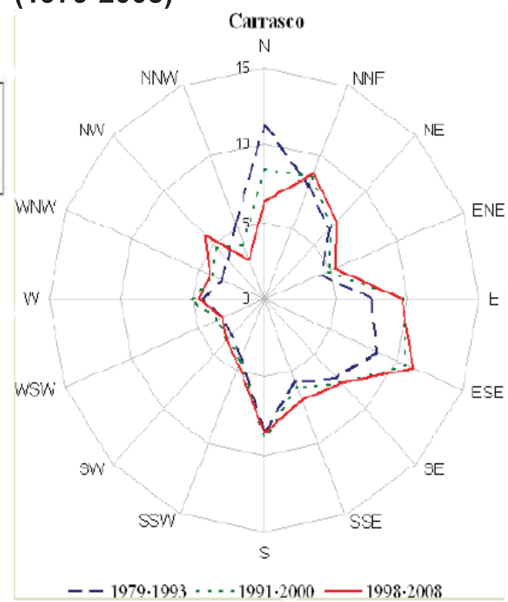


Figure 9 – Changes in the direction of prevailing winds (1979-2008)



Above: Average monthly wind speeds (km/hr) show a decreasing trend in three coastal stations (Carrasco, Colonia and Punta del Este) between 1961 and 2008. **Source:** Bidegain et al. (2009)

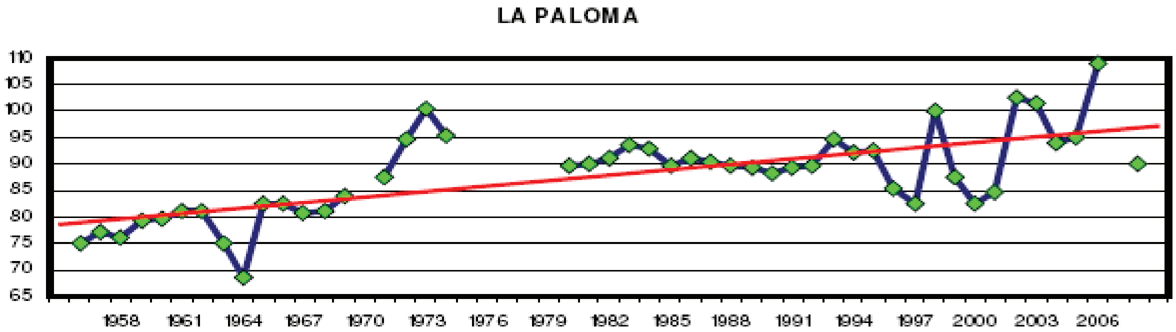
Right: Wind rose at Carrasco station. Concentric rings from centre to periphery represent percentages (0, 5, 10 and 15%) of annual wind directions. Winds with an easterly influence have increased and northerly winds have decreased between 1979 and 2008. **Source:** Verocai et al. (2009) as cited in Nagy (2011)

Observed sea-level rise in Rocha

Verocai et al. (2009) observe that average annual sea levels have risen more than 15 cm on the Atlantic coast of Uruguay (La Paloma, Rocha) between 1957 and 2008 (Figure 10). This is considerably more than observations on the coast of the Río de la Plata in Montevideo (ca. 200 km from La Paloma) that have risen approximately 11 cm in twice the amount of time (1902-2003) (Bidegain et al. 2005). Both stations observe a marked increase in variability over the past decades. Forcings on sea levels in the Río de la Plata are related to: i) the prevailing winds; ii) discharges from the principal tributaries (Paraná and Uruguay rivers); and iii) astronomical tides (Barros et al. 2005).

[3] Nagy, G.: personal communication, Mar. 22nd, 2011

Figure 10 – Annual average sea levels (cm) in La Paloma (1957-2008)



The red line indicates the long-term increasing tendency in annual average sea levels (cm) between 1950-2008 in the town next to the Laguna de Rocha (La Paloma). Note the increasing variability since the late 1980's. **Source:** Verocai et al. (2009)

Given that the coastline is considered micro-tidal (~40 cm) and that the Atlantic coast is only moderately vulnerable to changes in the tributary discharges of the Río de la Plata, the prevailing winds (especially from the southeast) are highly relevant (Re and Menendez, 2007). Nagy et al. (2007) estimate that an estimated 2/3 of the average 1.0 m sea level variability observed in Montevideo can be attributed to wind forcings, especially from the south-southeast.

Observed temperature changes

Several studies use observed data from Argentina, Uruguay and southern Brazil (among others) between 1900 and 2000 and the data suggests both average and extreme warming (e.g. less cold nights and more warm days) in Southeastern South America (Rusticucci and Barrucand, 2004; Bidegain et al., 2005, Vincent et al., 2005; Marengo and Camargo, 2007; Rusticucci and Renom, 2008). These studies show that the warming trend is present in both summer and winter, though stronger in winter than in summer and with considerable inter-annual variability. Increases in daily minimum temperatures (e.g. less cold nights, more warm nights) are particularly significant in the region, while the trend is not as clear for daily maximum temperatures. Extreme temperatures are also found to correlate with observed sea surface temperature (SST) anomalies in the coastal waters of both the Atlantic and Pacific Oceans. The highest trends of annual warming in Uruguay have been recorded on the Atlantic coast having risen nearly 1°C between 1961 and 2008 (Bidegain et al., 2009). Table 1 presents the temperature observations for the Rocha station.

Table 1 – Observed temperature averages, extremes and trends in Rocha

Temperature (T)		Period	Rocha (Uruguay)	Units	Source(s)
TAvg	Annual average	1961-2010	16.3	°C	DNM
	Change	1961-2010	0.2**	°C/10 yr	DNM
TMax	Summer days	1961-1990	102.5	Days	Vincent et al. (2005)
	Warmest day	1961-1990	39.5	°C	DNM
	Warm day change	1950-2002	-0.2 to 0	%/10 yr	Rusticucci and Renom (2008)
	Cold day change	1950-2002	-0.6 to -0.2*	%/10 yr	Rusticucci and Renom (2008)
TMin	Frost days	1961-1990	5.1	Days	Vincent et al. (2005)
	Coldest night	1961-1990	-5.8	°C	DNM
	Warm night change	1950-2002	0.6 to 1.0*	%/10 yr	Rusticucci and Renom (2008)
	Cold night change	1950-2002	-0.6 to -0.2 *	%/10 yr	Rusticucci and Renom (2008)

Indices follow definitions from Vincent et al. (2005): i) Summer days = # of days with TMax > 25°C; ii) Warmest day = Highest daily TMax; iii) Warm day = % of days with TMax > 90th percentile; iv) Cold day = % of days with TMax < 10th percentile; v) Frost days = # of days with TMin < 0°C; vi) Coldest night = Lowest daily TMin; vii) Warm night = % of nights with TMin > 90th percentile; viii) Cold night = % of nights with TMin < 10th percentile. DNM – Dirección Nacional de Meteorología. (*) corresponds to changes significant at the 95% level and (**) for significance at the 99% level.

Trends from the Rocha station agree with the regional tendency of more warm nights, fewer cold nights, fewer cold days and an insignificant change in the incidence of warm days (Table 1). Possible explanations for the change in extreme temperatures in Uruguay are offered from Rusticucci and Renom (2008) and Renom et al. (2010) who analyze the effects of SST anomalies and atmospheric circulation on the variability of warm nights (during winter) and cold nights (during summer). Their results show that changes in extreme temperatures are related to the global climate shift of 1976-77 that caused an observable change in Pacific SST and general atmospheric circulation over South America. According to these studies, current extreme temperatures, especially warm nights, since the shift (1976-2005) are more strongly associated with local atmospheric circulation patterns over the South Atlantic in both summer and winter compared to the previous period (1946-1975) that displayed much higher association with remote SST changes in the Pacific (ENSO).

Observed precipitation changes

In SESA, a positive trend in average and extreme precipitation over the twentieth century, especially the second half, has been observed by numerous studies (Barros et al., 2000; Haylock et al., 2006; Grimm et al., 2010 and references therein). Table 2 reports an alarming increasing linear trend in average annual accumulated rainfall of 6.7 mm per year between 1961 and 2010 in Rocha. Another noteworthy observation is that daily indices show a significant increase of 8-12 more days with heavy rainfall (e.g. more than 10 mm) between 1961 and 2000.

Table 2 – Observed precipitation averages, extremes and trends in Rocha

Precipitation (P)		Period	Rocha	Units	Source(s)
Annual	Annual average	1961-2010	1183	mm	DNM
	Annual change	1961-2010	6.7**	mm/year	DNM
	Seasonal change	1930-2000	0.0-1.0 (Fall) 1.0-2.0* (Winter) 1.0-2.0* (Spring) 1.0-2.0* (Summer)	mm trimester /year	Gimenez et al. (2006)
Daily	Heavy precipitation days	1961-2000	20-40	days	Rusticucci et al. (2009)
	Change in heavy precipitation days	1961-2000	8 – 12**	days/40 yr	Marengo et al. (2010)
	Very wet day proportion	1961-2000	20-25	%	Rusticucci et al. (2009)
	Consecutive dry days	1961-2000	0-30	days	Rusticucci et al. (2009)
	Consecutive dry days change	1961-2000	-10 – 0**	days/40 yr	Marengo et al. (2010)

Annual indices: i) Annual change estimated assuming a long-term linear trend between 1961 and 2010; ii) Seasonal change calculated as linear regression coefficients of changes in precipitation per trimester during 1930-2000. Daily indices follow definitions from Haylock et al. (2006): i) RR is the daily rainfall rate; ii) Heavy precipitation days = Annual # of days with RR ≥ 10 mm; iii) Very wet day proportion = % of annual total precipitation from days with RR ≥ 95th percentile of the 1961-1990 base period; iv) Consecutive dry days = Max # of consecutive days with RR < 1mm. (*) corresponds to changes significant at the 90% level; (**) corresponds to changes significant at the 95% level.

Like the temperature changes above, El Niño (La Niña) have been extensively studied and scientists believe they are the most important source of variability in circulation patterns and accompanying precipitation in all seasons, except summer, especially since the global climate shift of 1976-77 (Grimm et al. 2010). The changes in summer are attributed more to important sources of local variability including changes in: i) southwards displacement of the western border of the South Atlantic High; ii) SACZ intensity and position; and iii) an enhancement (decline) of moisture transport from the tropics to the sub-tropics in the SALLJ that increase (decrease) seasonal precipitation in SESA (Marengo et al., 2010 and references therein). More precipitation over SESA has also been linked to SST anomalies in the Western South Atlantic (Doyle and Barros, 2002).

2.2.3 Summary of Observed Changes to Climate in Rocha, Uruguay

Table 3 summarizes the climatic trends observed from the above assessment of the climate change literature as pertains to the Atlantic coast of Uruguay. In comparison to other parts of Uruguay, the Atlantic coast has recorded the highest increasing trends in temperature, precipitation and sea level rise.

Table 3 – Summary of observed climatic trends in Rocha, Uruguay

Sea level rise	Period	(see Section 2.2.3 and Figure 10)
	1957-2008	2.94 mm/year – Increase of 15 cm in the last fifty years[1].
Temperatures		(see Section 2.2.4 and Table 1)
Average	1961-2010	0.2°C/10 year – Significant increase of 1°C in the last 47 years[2]
Maximum	1950-2002	No significant change in warm days; Decrease in cold days[3]
Minimum	1950-2002	Increase in warm nights; Decrease in cold nights[3]
Precipitation		(see Section 2.2.5 and Table 2)
Average	1961-2010	6.7 mm/year – Increase of more than 300 mm in 49 years[2]
Heavy rain days	1961-2000	2-3 days/10 year – Increasing days with rainfall over 10 mm[4]
Dry days	1961-2000	Slight decrease in dry days[4]
Winds		(see Section 2.2.2 and Figures 7, 8 and 9)
Velocity (m/s)	1961-2008	Nearby stations on the Río de la Plata observe a decrease in wind velocities[5] Global models estimate no change in average wind velocities on the Atlantic coast of Uruguay[5]
Direction	1979-2008	Nearby stations observe increase in annual winds with an easterly influence and decrease in northerly winds[5] Regional models estimate increase in ‘summer’ circulation patterns with more easterly winds at the expense of the ‘winter’ pattern[6]

[1]Verocai (2009); [2] DNM data; [3]Rusticucci and Renom (2008); [4]Rusticucci et al. (2009); [5]Bidegain et al. (2009); [6]Barros et al. (2005)

Local changes to circulation patterns could not be assessed due to a lack of data, however an analysis of coastal stations nearby demonstrate an increase in winds with more of an easterly influence caused by the southward displacement of the western border of the South Atlantic high pressure system (Barros et al., 2005; Verocai et al., 2009 cit. Nagy, 2011). This chapter began with a top-down examination of the global climate system, what we know about how it can be changed and the known past and current climatic trends on the Atlantic coast of Uruguay. Now the task for the following chapter is to use these climate observations to analyze how these macro changes could affect the Laguna de Rocha ecosystem.

CHAPTER 3: ECOLOGICAL CHARACTERIZATION AND IDENTIFICATION OF ECOSYSTEM SERVICES VULNERABLE TO CLIMATE CHANGE IN THE LAGUNA DE ROCHA

"Economic analysis can only be as good as the physical science on which it is based"
(Glover, 2010)

3.0 Introduction

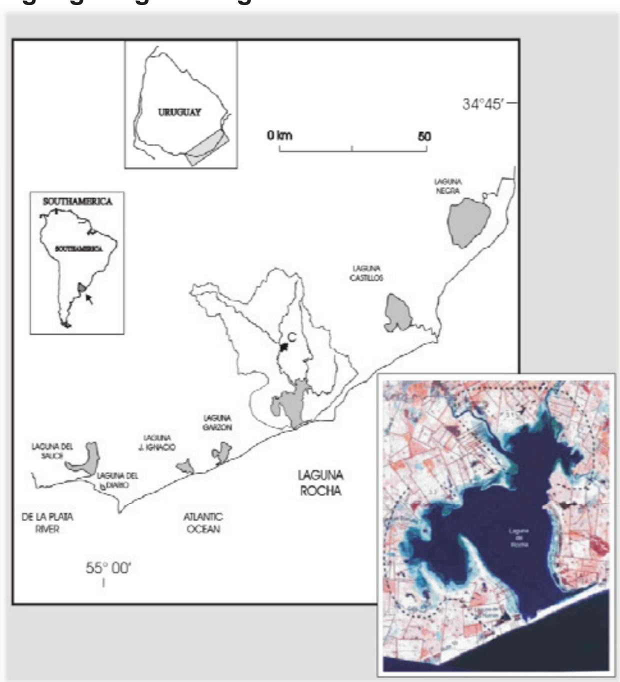
Coastal lagoons occupy roughly 13% of global coastal areas and are recognized among the most highly productive ecosystems on the planet (Barnes, 1980; Barbier et al., 1997; Troussellier and Gattuso, 2007). Their dynamism is due to the mixing of physical and biological characteristics from both marine and freshwater sources that occurs within inland water bodies separated from the ocean by barriers that only connect via one or more restricted inlets (Kjerfve, 1989). Lagoon ecosystem services contribute to human well-being directly through: i) the provision of foods, fibres and other products; and ii) their cultural, aesthetic and recreational importance. Furthermore, the supporting and regulating services of lagoon ecosystems benefit people indirectly in many ways, including climate regulation, nutrient cycling and protection from natural hazards (MEA, 2005). These ecosystems are particularly vulnerable to climate change and other anthropogenic stressors that degrade the ecological character of coastal lagoons and the services they provide to millions of people worldwide (Barbier et al., 1997). An understanding of the ecological and social characteristics of coastal lagoons is therefore required to manage their resources and services effectively in a sustainable and climate-resilient manner.

This chapter provides a brief physical and ecological characterization of the Laguna de Rocha Protected Area (LRPA) and analyzes how observed climate changes have impacted/could impact the biophysical environment of the protected area. An internationally recognized ecosystem assessment framework is adapted to identify and select LRPA ecosystem services vulnerable to the climatic trends observed in the previous chapter.

3.1 Biophysical Characteristics of the Laguna de Rocha Protected Area

The Atlantic coasts of Uruguay and southern Brazil are home to an important series of lagoons extending up the Uruguayan coast and culminating in the 10,200 km^2 Lagoa dos Patos (Brazil). The lagoon ecosystems along the Atlantic coast basin of Uruguay covering 9266 km^2 (Figure 11) provide food, water and the basis for local economic activities as well as protection from natural hazards and support for biodiversity of global importance (Conde et al., 2003).The LRPA (32° 40’ S, 54° 16’ W) is a 22,000 ha area located about halfway up the Atlantic coast of Uruguay (Figure 11). In 2010, the area received its current protected status and was incorporated into Uruguay’s National Protected Area System (NPAS)[4]. This fairly recent development builds on a long-standing recognition of the ecological importance of the lagoon ecosystem over at least the past thirty-five years[5].

Figure 11– Uruguayan coastal lagoons highlighting the Laguna de Rocha watershed.



Source*:* Department of Limnology, University of the Republic

The LRPA is a component of Uruguay’s only UNESCO Biosphere Reserve (since 1976) which is also recognized under the Ramsar Convention’s List of Wetlands of International Importance (since 1984). It is a designated Important Bird Area (IBA) site by Bird Life International for its more than two hundred species of migratory and resident populations that represent more than half of Uruguay’s total 435 bird species (Aldabe et al., 2009).

The lagoon ecosystem was recently designated a ‘Site of Regional Importance’ by the Western Hemisphere Shorebird Reserve Network (WHSRN) recognizing an important wintering site for 24 species of shorebirds, some of whom migrate from the Arctic, including 6.6% of the global population of Buff-breasted Sandpipers (*Tryngites subruficollis*) (WHSRN, 2011). Primary economically productive activities on the adjacent lands include extensive livestock-raising (beef, mutton and milk), agriculture (soybean,

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[4] Declared a Protected Area and incorporated into the National Protected Area System by National Decree *Nº 61/010* on February 18, 2010. See MVOTMA (2010) for the text, delimitation and approval of the protected area.

[5] Declared a National Park and Multiple-Use Area along with neighbouring lagoons by National Decree 260/77 (1977)

potatoes, fodder) and tourism. The lagoon itself is a nursery and habitat for numerous crustacean and fish species of economic importance (Sao Paulo shrimp *Penaeus paulensis*, blue crab *Callinectes sapidus*, white croaker *Micropogonias furnieri* and flatfish *Paralichthys orbygnianus*) (Fabiano and Santana, 2006).

The area is also unique in Uruguay because it is one of the few ecosystems in the middle-income country with physical and ecological information documented fairly regularly since the 1980's (Sommaruga and Pintos, 1991; Conde and Sommaruga, 1999; Bonilla et al., 2006). Indeed, from a biophysical perspective, the Laguna de Rocha is probably the best-known ecosystem in the country. This sub-section presents a brief summary of the literature from books, theses, peer-review journals and reports on: i) the origins and physical characteristics of the Laguna de Rocha; and ii) an ecological characterization of the protected area[6].

3.1.1 Origins and Physical Characteristics of the Laguna de Rocha

Geologically, lagoons are short-lived features of the landscape, whose dynamic existence is linked, among other things, to relative sea level changes caused by global climate change, tectonic activity and/or human activities (Kjerfve, 1994). Sediment cores taken from the Laguna de Rocha (LR) suggest that its origins can be traced back 7,000-5,500 years ago and have been linked to the maximum Holocene transgression when sea levels are estimated to have been between 4.0-6.5m above current levels on the Uruguayan Atlantic coast (García-Rodriguez et al., 2006; Inda et al., 2006).

Nowadays, the LR is a relatively large, shallow and highly dynamic coastal lagoon located in the Rocha Department. At the northern (limnic) end of the lagoon, there are three rivers that drain freshwater accumulated from the lagoon's 1,312 km^2 watershed. The most important of these rivers is the Rocha River (avg. discharge: 13.4 m^3/s) that also provides water to, and carries waste from, nearby Rocha City (pop. 25,500) (Sommaruga and Pintos, 1991; Table 4). A homogeneous vertical mixing of the water column is ensured through wind action on the shallow lagoon, however, a salinity gradient is often observed between the ~12 km separating the extreme northern end of

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[6] The kind support of Dr. Daniel Conde (Department of Limnology, University of the Republic) is acknowledged for providing time and literature that would otherwise have been difficult (and in some cases impossible) to access.

the lagoon from the southern (marine) end (Conde and Sommaruga, 1999). Table 4 describes the principal physical characteristics of the Laguna de Rocha.

Table 4: Principal Characteristics of the Laguna de Rocha

Coordinates:	54°15'W 34°37'S
Average Lagoon Area (km^2):	73
Protected Area (km^2):	220
Watershed Area (km^2):	1,214
Average depth (m):	0.6
Principal tributaries:	Rocha, Las Conchas, La Paloma, Los Noques (4)
Distance from the coast (km):	0.1
Connection with the ocean:	Frequent (Sand-bar open 48% of annual cycle; average 1991-1999)
Urban areas and settlements nearby:	Rocha City (pop. 25,500); La Paloma (resident pop. 3,500); Fishing villages (resident pop. +50)
Hydrological regime:	Primary ecological driver determining the degree of marine and freshwater mixing via the opening and closing of the sandbar
Principal economic activities:	Agriculture; extensive livestock-raising; fisheries; tourism;

Sources: Conde et al. (2003), Bonilla et al. (2006) and Rodríguez-Gallego (2008)

According to the lagoon classification scheme proposed by Kjerfve (1989) – choked, restricted or leaky – the LR can be considered 'choked' based upon its degree of exchange with the ocean by means of one single channel (Bonilla et al., 2005). This channel is frequently blocked by a sandbar that opens naturally under the combined forcings of: i) continental run-off causing the depth of the lagoon to exceed a given level; and ii) high wave and wind action on the seaward side (Bonilla et al., 2005) (Figure 12). As a result, the physical and ecological structure of the lagoon is highly variable depending on the prevailing hydrological conditions and whether or not the sandbar is open or closed (Bonilla et al., 2002).

Conde (2000) identifies three distinct hydrological phases of the Laguna de Rocha useful for understanding its ecological behaviour (Figure 13). The first phase is characterized by a closed sandbar; dominated by continental run-off that inputs high loads of dissolved and particulate organic matter throughout the water column (Conde et al., 2000). This phase continues until the combined forcings of increased lagoon water levels and oceanic wave action open the sand bar and drain the lagoon.

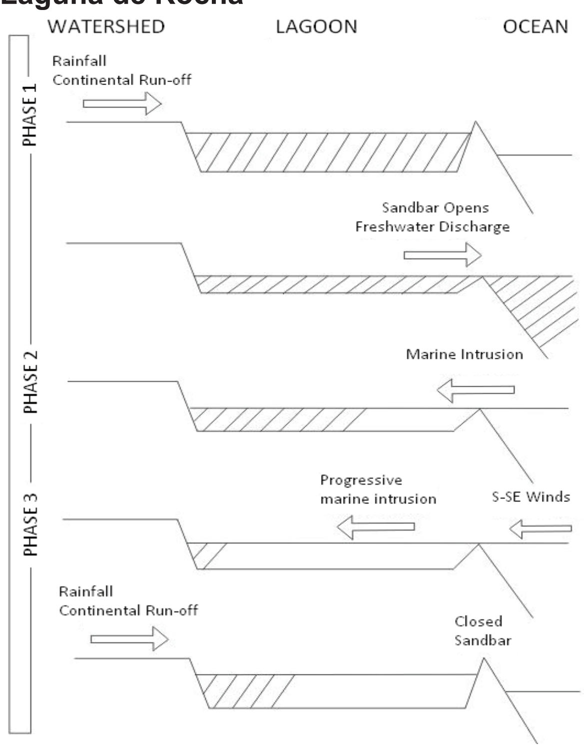
Following the freshwater discharge that can last anywhere from a few days to several weeks, Phase 2 is characterized by an intrusion of seawater into the lagoon usually under the influence of south-easterly winds. During this phase, a clear salinity gradient develops as nutrient-enriched freshwater at the southern end of the lagoon is diluted by seawater and turns brackish meanwhile the northern end remains limnic for longer (Bonilla et al., 2005). Phase 3 is essentially an intensification of Phase 2 whereby sustained south-easterly winds (e.g. several days) push saline waters even further north thus amplifying the extremes between limnic (turbid, nutrient-enriched) and marine (transparent, poor nutrient content) waters until eventually the sandbar closes again (ibid).

Occasionally, the sandbar is also opened artificially to decrease occasional flooding of adjacent grasslands used for livestock grazing and/or to permit the entry and maturation of commercially important marine larvae, especially shrimp (Santana and Fabiano, 1999).

Figure 12 – Laguna de Rocha Sandbar

Aerial views of the Laguna de Rocha sandbar: open (top left); closed (bottom left); and littoral profile (right). **Photos:** G. Chalar and H. Caymaris

Figure 13 – Hydrological Phases of the Laguna de Rocha



Three distinct hydrological phases, characterized by continental run-off or marine intrusion, determine the ecological behaviour of the Laguna de Rocha. **Source:** Adapted from Conde (2000).

Ecological ramifications of sector-specific decisions to open the sandbar have yet to be analyzed despite widespread recognition that the opening and closing of the sand bar is the primary driver of the physical and ecological structure of the lagoon (Conde et al., 2003; Rodriguez-Gallego et al., 2008). An important first effort currently underway by an interdisciplinary team from the local university is to design a multi-criteria decision support tool for informing the artificial opening of the sandbar (D. Conde, pers. comm., Oct. 12, 2011). An output of the above project is to build a hydrodynamic model of the lagoon that could, among other things, permit a monetary valuation of expected damages to adjacent lands from increasing frequency/intensity of southeasterly storms.

3.1.2 Ecological Characterization of the Laguna de Rocha Protected Area

The Laguna de Rocha Protected Area (LRPA) can be characterized ecologically as: i) the brackish lagoon water body itself along with adjacent freshwater ponds and tributaries; ii) the coastal littoral zone comprising dunes, beaches and the connection between lagoon and ocean; iii) the marine zone extending 5 nautical miles out to sea; and iv) rolling hills, floodplains and prairies (Probides, 1999) (Figure 14).

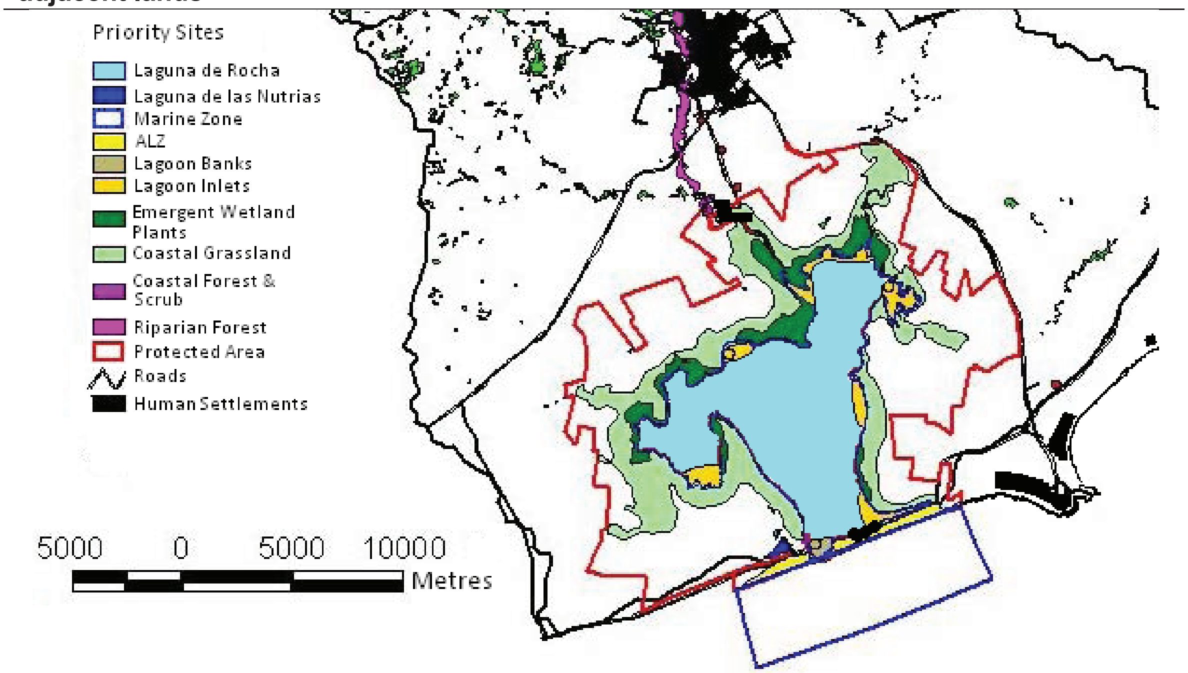
From a biological perspective, primary producers in the highly productive lagoon include microphytobenthos (microalgae attached to lagoon substrate), phytoplankton (microalgae in the water column) and macrophytes (aquatic plants) (Bonilla et al., 2006). In terms of microalgae biomass, the phytobenthos are the dominant group forming 96% (northern end) and 85% (southern end) of average annual chlorophyll *a* in the lagoon (Conde et al., 1999). Phytoplankton biomass fluctuates between 4.2 and 32% of the total and has been related to the opening and closing of the sandbar based on the euryhaline composition of species observed (Bonilla et al., 2006). A bloom of the toxic phytoplankton cyanobacteria *Pseudanabaena* cf. *moniliformis* was registered for the first time in 2003 that could cause adverse impacts on higher trophic levels (including fisheries) and recreational uses of the lagoon if found to be recurring (Conde et al., 2009). The probable causes of the 2003 harmful algal bloom have been related to climatic phenomena in the region as opposed to land use changes in the lagoon watershed (ibid).

Milessi et al. (2010) develop an ecological model of the food web structure of the lagoon ecosystem based on 27 species including primary producers, bivalves, crustaceans, fish, birds and mammals. They identify 4.20 trophic levels and further estimate that

Mysids (a group of shrimp-like crustaceans) are the central group linking lower level primary producers (microalgae, macrophytes) and consumers (bivalves, snails) to the higher trophic levels (fish, migratory birds, otters).

Taking an ecosystem approach, Rodriguez-Gallego et al. (2008) identify nine sub-ecosystems of importance for conservation within the delimitated LRPA that are briefly described in Table 5 and mapped in Figure 14. Additionally, they highlight the importance of the riparian forest and wetlands of the Rocha River (and other tributaries, to a lesser degree) that are technically outside the designated protected area but that perform valuable water quality maintenance and purification services of wastewater from Rocha City before draining into the lagoon.

Figure 14 – Priority zones for conservation in the Laguna de Rocha Protected Area and adjacent lands



Human settlements (in black) include Rocha City (top centre), La Paloma, Costa Azul and La Pedrera (bottom right from left to right), fishing villages and La Riviera village (at southern and northern ends of the LR). Borders to the left- and upper right-hand sides of the image represent the western and eastern limits of the lagoon watershed, respectively (upper watershed not shown). White areas represent grasslands and prairies used for extensive livestock-raising or, to a lesser degree, agricultural lands. **Source**: Adapted from Rodriguez-Gallego et al. (2008)

Table 5 – Ecological zones of importance for conservation in the Laguna de Rocha Protected Area

Zone	Area (ha)[1]	Description
Laguna de Rocha water body	7304	Highly productive water body of economic importance for its function as a nursery and feeding ground of numerous species of fish and crustaceans (including most developed inland fishery in Uruguay with highest 'catch per unit effort' of all the coastal lagoons[2]. Other important social values include biodiversity appreciation, tourism, sense-of-place, scholarly research, etc.).
Laguna de las Nutrias water body	44	Small freshwater lagoon located near the littoral zone with high biodiversity and scenic value including coastal forest, nesting/feeding site for otters, capybaras, numerous birds and freshwater fish[3].
Marine zone	7519	Waters and seafloor of the Atlantic Ocean extending 5 nautical miles from the active littoral zone characterized by the confluence of the Brazil and Malvinas currents as well as freshwater inputs from the Uruguay and Paraná Rivers. Nursery/feeding site for economically important fish species and habitat for cetaceans and sea turtles.
Active Littoral Zone (ALZ)	399	Interface between ocean and land characterized by constant sediment transport and dynamic equilibrium that can be sub-divided into zones according to: i) wave action from where breaking waves begin to form in the ocean to the swash (infra-ALZ); ii) both wave and wind action from the swash to the generation of frontal dunes (meso-ALZ); and iii) wind action from the dunes to farthest point inland that sands are carried (supra-ALZ). Performs multiple ecosystem functions including storm protection and important habitat for priority species of both flora and fauna (e.g. coastal scrub, amphibians, birds).
Lagoon Banks & Channel	129	The lagoon banks of the ALZ, formed by the currents caused by the opening and closing of the sandbar, are recognized for their critical importance to the ecological functioning of the ecosystem. Located at the southwest extreme of the lagoon (see Figures 12 and 14), this is the only area where the ocean and lagoon connect and allow the entry/exit of marine species of economic importance and is also the area with the highest concentrations of numerous bird species of priority for conservation.
Lagoon Inlets	846	Shallow bays at the mouths of the principal tributaries that drain into the lagoon rich in organic matter and less exposed to coastal winds permitting the growth of aquatic plants throughout the whole year. None of the other coastal lagoons in Uruguay share this characteristic making these plants an important food source for resident swan populations and other species.
Emergent wetland plants	2064	Various species form a wetland at the northern end of the lagoon exposed to highly fluctuating water levels and salinities that determine the coverage and dominance of more or less saline-tolerant species. Provide habitat for bird species, erosion protection and water purification services.

Zone	Area (ha)[1]	Description
Coastal grassland	4907	Short, thick grassland encircling the lagoon water body of high importance as migratory bird habitat. In combination with adjacent natural prairies, this is the zone that makes the Laguna de Rocha a preferred habitat that for several endangered migrating shorebirds from the Arctic (including the Buff-breasted Sandpiper and at least 10 other species registered in Annex I or II of the Convention on Migratory Species)[4].
Coastal forest and scrub	6.4	A small area of endangered endemic thorny vegetation and associated fauna close to the Laguna de las Nutrias of importance for conservation due to its near-complete removal from the Uruguayan coast.
Rocha River riparian forest*	284	Combination of riparian forest and emergent wetland plants found along the Rocha River between Rocha River and La Riviera village at the northern end of the lagoon. The Rocha River receives effluents from the primary sewage treatment facility, municipal slaughterhouse and other more diffuse sources (unconnected septic tanks, sewers, etc.) in Rocha City that are not detected at the mouth of the river. The removal of the high nutrient loads associated with such effluents (that would otherwise favour eutrophication of the lagoon) is attributed to the water purification services of the riparian forest and wetland vegetation.

Sources: Rodriguez-Gallego et al. (2008) unless indicated otherwise.[1] Areas are calculated in Rodriguez-Gallego et al. (2008) from a 2005 summer Landsat Image and field validation; [2]see Fabiano and Santana (2006); [3] see Sarroca et al. (2009);[4] see Aldabe et al. (2006). (*) not included in the currently delimitated protected area.

The discussion in this section has been focused on the priority zones for conservation and ecosystem functions of the protected area. That being said, the majority of the lands within the LRPA are privately owned prairies and grasslands (either natural or fertilized) used for extensive livestock-raising or, to a much lesser extent, converted for intensive agriculture use (soybean and potato). Recognizing the multiple uses of the LRPA ecosystem, the task for the next section is to attempt to disentangle the numerous benefits provided by protected area to its human users.

3.2 Selection of Ecosystem Services Vulnerable to Climate Change

Based on the ecological characterization in Table 5 above and the identification of climatic trends from Chapter 2, specific ecosystem services vulnerable to climate change in the LRPA can be identified. Ecosystem services are defined by the Millennium Ecosystem Assessment (MEA, 2005) simply as “the benefits humans derive from nature” arising through the pathways from ecosystem structure and processes to human decision-making and well-being. Despite the simplicity of the above definition, attempts to disentangle the myriad ways that ecosystems support human life and well-being has led to much debate surrounding the appropriate means of classification (Costanza, 2008; de Groot et al., 2010 and references therein). That being said, considerable progress in understanding the complex interactions between human-ecological systems have been made even as most studies recognize that there may be no *final* classification scheme and borrow or tailor others to suit their own particular objectives. In a similar vein, this study will follow the recent ecosystem service classification proposed by *The Economics of Ecosystems and Biodiversity* (TEEB) study which is itself adapted from MEA (2005) and other sources (de Groot et al., 2010).

Essentially, Table 6 divides eleven ecosystem services identified for the LRPA into the four categories proposed by de Groot et al. (2010): i) provisioning; ii) regulating; iii) habitat; and iv) cultural. Within these ecosystem services, specific LRPA ‘items’ vulnerable to climate change impacts are identified along with the zone(s) where they can be found as shown in Figure 14. Justification for ecosystem service selection was made by borrowing heavily from the social and ecological characterizations provided by Rodriguez-Gallego et al. (2008) and integrating them with the climatic trends summarized in Chapter 2 of this report. Beyond the literature reviewed here, professional opinion was obtained through semi-structured interviews with experts at the Uruguayan University of the Republic and Ministry of Environment. As well, first-hand observations, attendance of two LRPA Advisory Commission meetings and consultations with local stakeholders were conducted during three field visits to the LRPA and adjacent areas.

The list of ecosystem services presented in Table 6 will be used to assess the relevance and feasibility of various monetary valuation methodologies to estimate economic impacts of climate change in the LRPA. The limitations of classification are recognized due to the multiple services provided by one ecosystem component (e.g. catching fish provides food *and* social identity to artisanal fishers in the Laguna de Rocha; emergent wetland plants provide water purification *and* erosion control). However, as mentioned above, a clear classification scheme of ecosystem uses is needed in order to proceed with the economic analyses.

Table 6 – Identification of ecosystem services vulnerable to observed climate changes in the LRPA

Ecosystem Services	LRPA Item	Zone	Justification
Provisioning			
Food	Commercial fish and crustaceans	LR; ALZ (sand-bar); Marine zone	Subsistence/recreational use vulnerable to changes in water quality from precipitation extremes and sea level rise
Fuel & fibre	Natural grasslands & prairies	Coastal grassland; Medium and high plains	Fodder and agriculture vulnerable to precipitation extremes and soil/aquifer salinization
Regulating			
Flood & storm protection	Dunes; LR water body	ALZ; LR; Coastal grassland	Laguna de Rocha, low-lying adjacent lands and littoral zone vulnerable to extreme precipitation, shift in prevailing winds and sea level rise
Pollution control	Emergent wetland plants; Riparian forest*	Northern wetland; Rocha River (and other tributaries)	Water purification services vulnerable to increased run-off from extreme precipitation and salinization
Erosion control	Dunes; Emergent wetland plants	ALZ; northern wetland	Erosion control vulnerable to extreme precipitation, shifts in prevailing winds/waves and sea level rise
Carbon sequestration	Emergent wetland plants	Northern wetland; lagoon inlets	Vulnerable to precipitation extremes and salinization
Habitat			
Maintenance of life cycles of species	Migratory birds; Resident species	All zones, especially the LR and sandbar (ALZ)	Ecological resilience vulnerable to increasing extreme events, sea level rise and wind changes
Cultural			
Recreational	Tourism	ALZ; LR; Laguna de las Nutrias; villages	Recreational uses vulnerable to changes in water quality, erosion, fish and bird habitat from all climate change stressors
Educational	Formal & informal education/training	All zones	Educational uses vulnerable to extreme events and sea level rise
Aesthetic	LRPA	All zones, especially LR and ALZ	Aesthetic appeal vulnerable to precipitation extremes in particular
Spiritual & Inspirational	LRPA, especially fishing communities	All zones, especially LR and sandbar of the ALZ	Sense of place and informal local traditions vulnerable to changes in water quality, erosion, fish and bird habitat from all climate change stressors

LR: Laguna de Rocha; ALZ: Active Littoral Zone; **Sources:** Typology adapted from MEA (2005) and de Groot et al. (2010). (*) not included in the currently delimitated protected area.

3.3 Taking Stock and Next Steps

Through an extensive literature review, expert consultation and field visits to the RLPA, Chapters 2 and 3 of this study sought to answer what specific environmental components of the protected area are vulnerable to observed climatic trends on the Atlantic coast of Uruguay. Increases in average/extreme precipitation and temperature, sea level rise and a shift in mean circulation patterns have been observed. The ecological zones vulnerable to these climatic trends have been linked through an analysis of the physical and ecological characteristics of the protected area and their ecosystem services were identified through an internationally recognized ecosystem assessment framework. Specific ecosystem components and their geographic zones were selected for the monetary valuation feasibility analysis by integrating socio-economic characteristics identified in: i) Rodriguez-Gallego et al. (2008); and ii) social scoping exercises with local stakeholders in the LRPA. While it is unlikely for any single classification scheme to capture the multiple benefits provided by a given ecosystem, the scheme chosen was adapted from the state of the art in the economics of ecosystems and biodiversity literature.

Based on the observed climatic trends and identification of ecosystem services from the previous chapters, the remainder of this study will move beyond physical impacts to discuss how people value the benefits provided by ecosystems. The next chapters will: i) define the strengths and limitations of valuing ecosystems in monetary terms and specific valuation methods for estimating the economic impacts of climate change in the LRPA; and ii) demonstrate applicable valuation methodologies for select ecosystem services in the protected area.

CHAPTER 4: ECONOMIC VALUATION OF CLIMATE CHANGE IMPACTS ON ECOSYSTEMS: CONCEPTUAL ISSUES AND FRAMEWORK FOR ANALYSIS

"One studies economics to avoid being fooled by economists" (Joan Robinson)

4.0 Introduction

The past few decades have witnessed a growing body of literature concerned with analyzing different notions of value and proposing methodologies for valuation relevant to decision-making on the human uses of ecosystem services (Farber et al., 2002; de Groot et al., 2010). The economic valuation of environmental issues is often controversial because of conceptual and methodological challenges related to placing a monetary value on changes in ecosystem components not typically associated with economic markets – e.g. non-market impacts (Rothman et al., 2003). Monetary valuations of non-market ecosystem services are usually undertaken using the argument that a common metric allowing for their comparison with economic services and manufactured capital is needed in order to inform policy decisions (Costanza et al., 1997a). Environmental economists have designed numerous valuation methodologies that attempt to correct these so-called market and policy 'failures' in order to better account for the economic value of ecosystem services to society in policy-making (Glover, 2010).

Stern (2007:1) refers to climate change as the "greatest example of market failure we have ever seen". Non-market impacts associated with climate change are estimated to make up a very significant share, if not the majority, of the total expected impacts (Tol et al., 2000; Rothman et al., 2003). That being said, in Uruguay – and many other countries – very few estimates of the local costs of climate change impacts exist and those that do rarely take into account the non-market value of ecosystems impacted by a changing climate (Parry et al., 2007). Credible estimates of the total costs and benefits of climate change, including adaptation costs, are very relevant for developing countries in the context of international climate change negotiations on development assistance, emission rights allocations and compensation for damages (Stage, 2010). In particular, estimates of the local costs of climate change impacts are needed in order to allocate adaptation funding efficiently in developing countries (Agrawala and Fankhauser, 2008; Parry et al., 2009; World Bank, 2010).

But how does one go about estimating the local costs of adaptation to climate change? First of all, the economic analysis needs to be based on an understanding of the physical environment and the stresses people put on it (Glover, 2010). For the purposes of this study, the climatic trends identified for Rocha in Chapter 2 and the selection of ecosystem services of the Laguna de Rocha Protected Area (LRPA) in Chapter 3 provided the all-important physical basis needed to inform the economic analysis of the non-market impacts of climate change. The next questions to explore move beyond what ecosystem services are physically provided in the LRPA and ask what those services are worth to people. What is the economic notion of value and what valuation methodologies are relevant for estimating the costs and benefits of the selected ecosystem services? Which methodologies can be feasibly implemented and what are the data needs? The idea is that a close look at the different methodologies and information available for the monetary valuation of ecosystem services (in the context of climate change in the LRPA) is needed to provide the most appropriate economic estimation of their value.

This chapter provides a brief introduction to some of the more controversial conceptual issues surrounding ecosystem valuations and describes a framework for analysis and assessment approaches relevant to the economic valuation of climate change impacts. First, different notions of 'value' and some of the limitations of valuing ecosystems using an economic framework are discussed. A two-tiered decision-making structure based on public reflection, action and evaluation is described as a means to understand the role of economic valuations in the broader decision-making process. Finally, economic assessment approaches for valuing the LRPA ecosystem services vulnerable to climate change will be analyzed using the Total Economic Value (TEV) framework.

4.1 Concepts of Value, Limitations and the Role of Ecosystem Valuations in Decision-making

Beginning with Plato and Aristotle, the history of western philosophy is filled with attempts to establish the role of values in questions surrounding ethics and moral judgements, such as what is morally right or wrong, good or bad, responsible or just (Zimmerman, 2010). Without delving too deeply into nearly 2,500 years of philosophical debate, value will be defined here using the widely cited definition from Costanza (2000:7) as "the contribution of an item to meeting a specific goal or objective". The specific goals or objectives that give rise to an item's value - whether that item is a hockey player, a coastal lagoon or a night's stay in a 5-star hotel – ultimately originate in societal norms and institutions – or value systems – that guide human judgements and action (Farber et al., 2002). Valuation can therefore be seen as the practice of expressing a value for a given action or thing, thus allowing for observation, measurement and some degree of comparison with other valued actions or things (ibid). In our case, the valuation under discussion is to express the *economic* value of climate change impacts on the ecosystem services of the Laguna de Rocha Protected Area. In expressing economic value using monetary valuation methods, it's important first to be clear about the underlying goal of neoclassical economics[7] in comparison to other social goals that logically each have their own values.

4.1.1 Utilitarianism and Neoclassical Economics

Mainstream economics is grounded in the philosophy of utilitarianism arguing that the morally right action is the action that produces the most good for the greatest number of people (Goulder and Kennedy, 1997). Utility is understood to be a measure of relative satisfaction or pleasure leading many utilitarians to call for society to be organized so that total individual utilities are maximized (Driver, 2009). Using the definition of 'value' from the previous paragraph: *a good or service's economic value can be seen as its contribution to the goal of individual utility maximization* (Costanza, 2000). An important point to note is that economic value is profoundly *instrumental*: things are only economically valuable as instruments towards the ultimate satisfaction of the *intrinsic* good of human pleasure or utility (Goulder and Kennedy, 1997).

A long-standing problem with utilitarian reasoning as a practical means to organize society is that relative utility (human pleasure) cannot be meaningfully measured and compared directly across people (Marshall, 1920). It is difficult to convincingly quantify the pleasure I experience, for example, from spending a sunny day at the beach that permits a direct comparison with the pleasure you experience from that same sunny day. The economists' solution has been to measure utility indirectly using a specific set of assumptions regarding the preferences revealed when individuals are observed making choices for one good over another at market prices and always in the presence of constraints (Farber et al., 2002). Using the example of my sunny day at the beach, economists assume that my utility *is* higher than yours if I, given my limited resources,

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[7] The terms 'neoclassical', 'conventional' and 'mainstream' are used interchangeably throughout the text.

am willing to pay more than you both directly (e.g. transport and user fees) and/or indirectly through the opportunity cost of time spent at the beach not spent doing something else (e.g. working).

Neoclassical economic theory seeks to determine the optimal price of a given good in a market through the equilibrium quantity of demand and supply governed by the circular flow of exchange between households (consumers, labour) and firms (producers, employers) (Weintraub, 2007). It builds upon three central assumptions: i) people have rational preferences among outcomes; ii) individuals maximize utility and firms maximize profits; and iii) people act in their own self-interest on the basis of complete information (ibid). Contemporary branches of economic thought concerning consumers, producers, welfare, labour, the environment, etc. are built upon these three central assumptions that have also led to many critiques of the conclusions based upon the simplistic behaviour of the neoclassical *Homo economicus* (Persky, 1995).

4.1.2 Conceptual Limitations of the Economic Valuation of Ecosystems

Critiques of the assumptions of economics are not new. Indeed, Persky (1995) provides a historical account of critiques of *Homo economicus* dating back to the early 19th century. This section identifies four broad limitations from the literature related to the economic valuation of ecosystems: i) intrinsic values; ii) different forms of utilitarianism; iii) equity issues; and iv) sustainability issues.

<u>Intrinsic values</u>

Some people feel that protecting the environment and/or other species from harm has a value beyond the contribution to utility it gives to the person or society doing the protecting. Rather, it is argued that an ecosystem or species has an intrinsic right to a healthy and prosperous condition that ought to be protected on moral grounds independent of whether or not humans derive satisfaction from it (Farber et al., 2002). *The value in protecting an ecosystem in this view would be the contribution of that protection towards the goal of ecological sustainability*. Most importantly, the two goals discussed so far – ecological sustainability and utility maximization – generate different, and possibly conflicting, concepts of what policy or action would be considered ‘valuable’ even when dealing with the same ecosystem. In practice, the argument for recognizing the intrinsic rights of ecosystems on par with human rights moves beyond adding up ecosystem ‘values’ altogether and would instead base the decision-making process on whether or not such rights would be violated by various policy alternatives (Goulder and Kennedy, 1997). In this case, conventional economic analysis has little to offer decision-makers.

Strong and weak forms of utilitarianism

Many ecologists and economists can agree on a utilitarian notion of value if one defines the concept of utility broadly enough to allow ecosystem goods and services to contribute to individual satisfaction: i) directly (consumption, recreation); ii) indirectly (flood protection, erosion control); and/or non-uses (simply knowing something exists) (de Groot et al., 2010). Goulder and Kennedy (1997) refer to this as a 'weak' form of utilitarianism. The authors distinguish between 'weak' and 'strong' forms of utilitarianism in order to help explain the uneasiness many ecologists feel with respect to monetary valuation of ecosystems in economic cost/benefit analyses (CBA). Essentially, the strong form of utilitarianism makes the additional assertion that the value of an ecosystem service to *society* can be obtained by adding up *individual* utility values. This strong form of utilitarianism is inherent in CBA and convenient as a means to rank aggregate net benefits across alternative policy options. However, it makes many ecologists nervous when it comes to poorly understood ecosystem services because it accords equal weight to all individual preferences in society when aggregating those net benefits (Goulder and Kennedy, 1997). In other words, ecologists (and others) argue that some people's preferences ought to count more than others (e.g. expert opinion) when deciding upon human uses of highly non-linear ecosystems. This is especially true when it comes to the uncertain science of recognizing critical ecological thresholds – or tipping points – whose crossing would cause irreversible and potentially catastrophic consequences (Farber et al., 2002). In this view, an intermediate position that will be adopted here is that cost/benefit analysis alone is not sufficient to determine the best policy option that would impact a given ecosystem however it can be useful for providing information necessary to weigh various alternatives[8].

[8] See Vatn and Bromley (1994) for a more extreme position claiming that monetary valuations of ecosystems are neither sufficient *nor* necessary for decision-making about the environment

Equity issues

There is a long-standing debate in welfare economics surrounding the supposed trade-offs between equity and efficiency (Dinwiddy and Teal, 1996). Essentially, conventional microeconomic analysis begins with a given endowment among individuals and/or allocation of productive assets among firms that can be re-allocated more efficiently according to the Pareto criterion (ibid). A Pareto efficient allocation is one where it is impossible to re-allocate commodities or factors of production that would make one person better off without making somebody else worse off (Varian, 2005). By accepting given endowments or allocations as their starting point of analysis, conventional economists are criticized for ignoring questions surrounding distributional justice between: i) rich and poor (equality); and ii) present and future generations (intergenerational equity) (Costanza, 1997b). For the latter, much research has gone into the appropriate selection of discount rate(s) for expressing individual time preferences though the issue remains provocative, especially for long time horizons (Gollier and Weitzman, 2010). For the former, distributional weights are sometimes placed on particular (usually disadvantaged) groups' benefits in cost/benefit analyses though this practice is also controversial (Harberger, 1978).

Contrasting views of sustainability

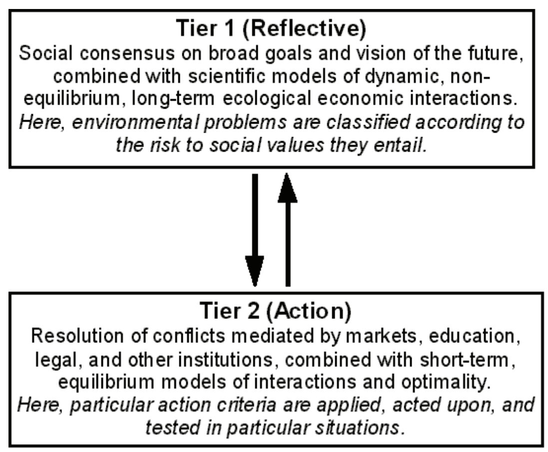
Conventional economic models often imply perfect substitution between stocks of manufacturing capital, human capital and natural capital (e.g. that they are equally valuable) so that the neoclassical criterion for sustainability rests on maintaining total *net* capital stocks (Gowdy, 2000). According to this logic, if Country A degrades their environment but replaces the monetary value of natural capital stock lost with manufacturing capital stock so that flows of total output remain the same (or increase), then Country A is behaving sustainably. In contrast, the ecological economics school generally argue from a 'strong' sustainability perspective that natural capital stocks are not perfectly substitutable and should be accounted for apart from other forms of capital (Rees, 2003). This implies that Country A was not behaving sustainably if natural capital stocks decrease *regardless of the effect on manufacturing capital stocks and total output flows*. Area-based measures of 'strong' sustainability such as the 'ecological footprint' typically report the consumption patterns of industrialized countries as the most unsustainable (Rees and Wackernagel, 1994). At the same time, the neoclassical monetary measures explored in this study correspond to the notion of 'weak' sustainability that usually reports these same countries as sustainable (Arrow et al., 2004)[9].

4.1.3 Two-tiered Approach to Decision-making

From the conceptual limitations identified above, three largely independent social goals arise: i) ecological sustainability; ii) just distribution; and iii) allocative efficiency (Daly, 1992). Mainstream economic models assuming perfect substitution between capital stocks and striving for Pareto efficiency have little or nothing to say with respect to the first two goals. This is not to throw away conventional economic models altogether but merely to recognize their role in the greater decision-making process that must confront ecological and social realities in our increasingly 'full' world (Costanza et al., 1997b).

Norton et al. (1998) provide a useful two-tiered approach to decision-making that helps define the role of ecosystem valuations and CBA (Figure 15). The first tier is reflective and requires social goals to be built around a vision of the future shaped by public discourse and negotiation or "value formation through public discussion" (Sen, 1995). The second tier puts the social goals agreed upon into practice by selecting decision-making mechanisms (including, inter alia, CBA) for specific contexts.

Figure 15 – Two-tiered decision structure



Source: Norton et al. (1998)

It is here that the relevance of the present study arguing for a deeper understanding of how monetary valuation methodologies for eliciting the economic values of non-market climate change impacts can be found. Essentially, the reflective tier has built/is building social consensus around the argument that anthropogenic climate change poses a threat to other social goals (for example, the Millennium Development Goals) leading to calls for action that reduce environmental risks through context-specific management policies (e.g. adaptation and mitigation) (World Bank, 2010). Cost/benefit analyses (with

[9] See Wilson et al. (2007) for a review and analysis of weak and strong sustainable development indicators

accompanying monetary valuations of non-market climate change impacts) are argued to provide decision-making criteria for choosing the ‘best’ option among various policy alternatives (Stage, 2010). Importantly, the arrows moving in both directions in Figure 15 are meant to show that it is possible to return to the reflective tier to re-examine the choice of cost/benefit (or any other) criteria in the action tier based on new evidence from decisions made (Norton et al., 1998). It is argued here that the general objective of this research project – testing the feasibility and relevance of monetary valuation methodologies for estimating the costs of climate change impacts in the LRPA – provides information relevant to concrete management decisions in the protected area (action tier) and could also inform international discussions on the relevance of local monetary estimates of climate change impacts in developing countries (reflective tier).

4.2 The Environmental Economics of Climate Change: Conceptual framework and Assessment Approaches

Economics has been defined as a “science which studies human behaviour as a relationship between ends and scarce means which have alternative uses" (Robbins, 1932). Several general points are worth elaborating from the above definition. The first is to note the use of the word ‘science’: Robbins’ definition places Economics firmly in the ‘positivist’ camp concerned only with Pareto efficient allocations (e.g. not concerned with distributional or ecological sustainability issues discussed in the previous section). Second, as mentioned above, Economics is a utilitarian social science focused on how *humans* allocate scarce resources. For better or for worse, it is not concerned with the ‘ends’ of any other species. Third, the ‘relationship between (unlimited) ends and scarce means’ is *relative* with choices made by weighing people’s preferences for one good as compared to those of another (McFadden, 2001). This comparison is facilitated by using a common metric for all goods – money. However, it is important to remember that money itself has no value except as a means to purchase the things that people really care about (Simpson, 1998). Fourth, the circumstances that lead to a (relative) preference for one good over another can *change* with resulting impacts on the economic value of the goods chosen to satisfy our (unlimited) wants (ibid). Finally, some ‘goods’ and ‘services’ definitely have value to people but are not traded in markets because they’re freely available to everybody in society (e.g. public goods). Hardin (1968) coined the term ‘Tragedy of the Commons’ for this failure of markets in allocating scarce resources efficiently because of *externalities* – the disjoint between the benefits that a firm (individual) receives from producing (consuming) a given good and the costs of that good borne by society as a whole.

The subfield of *Environmental* Economics that arose during the second half of the twentieth century is largely concerned with 'internalizing' negative externalities and correcting market failures – the inefficient allocation of goods and services by a free market under the Pareto criterion – identified in the economics literature at least as far back as Pigou (1920) (Costanza et al., 1997b). Environmental Economics attempts to address these market failures by trying to get the prices 'right' so that the costs to firms of producing a given good are equal to the costs borne by society, usually through some form of corrective tax or liability (Shavell, 2010). The following subsections discuss a theoretical framework and assessment approaches for undertaking an economic valuation of climate change impacts in the LRPA.

4.2.1 Total Economic Value

The most common framework for conceptualizing the different types of economic value provided by ecosystems is called Total Economic Value (TEV) (Pearce and Turner, 1990; Abeygunawardena, 1999; de Groot et al., 2010). The TEV framework conceptualizes total economic value as the sum of economic 'use' and 'non-use' values of ecosystem services. 'Use' values include the provision of materials directly for production/consumption (e.g. fish) and also 'indirect' regulatory services such as pollution control (CBD, 2007). 'Insurance' values are also classified here under 'use' values associated with maintaining the *option* of direct or indirect use in the future for a variety of reasons (e.g. self-interest, altruism, uncertainty) (Baumgärtner, 2007). 'Non-use' values typically refer to bequest and existence values – the values associated with passing consumption options to future generations and from knowing that ecosystems/biodiversity will continue to exist, respectively (Abeygunawardena, 1999). Figure 16 provides a conceptual mapping of the ecosystem services identified in the LRPA into the TEV framework. Common monetary valuation methods used for each category are also identified (to be discussed further in the next chapter).

Figure 16 – Conceptual mapping of LRPA ecosystem services in Total Economic Value framework

TOTAL ECONOMIC VALUE (TEV)

USE VALUE → Direct use value; Indirect use value; Insurance value

NON-USE VALUE → Existence value

TEV Categories	**Direct use value** Consumptive and non-consumptive	**Indirect use value** Regulatory/ecological services	**Insurance value** Maintain options for future direct or indirect uses	**Existence value** Altruistic or bequest
Laguna de Rocha ecosystem services	Natural grasslands & prairies	Flood/storm protection; Pollution control	Biodiversity as insurance against uncertain provision and/or regulation of ecosystem service	Designated protected area to preserve aesthetic, spiritual & inspirational value
	Commercial fishery	Carbon sequestration		
	Tourism	Erosion control		
	Formal & informal education/training	Habitat maintenance		
Common valuation methods	Change in productivity; hedonic prices; travel cost; cost-based approaches; stated preferences	Change in productivity; cost-based approaches; stated preferences;	Change in productivity; cost-based approaches; stated preferences	Stated preferences

Sources: Adapted from CBD (2007) and Barbier et al. (1997)

4.2.2 Economic Assessment Approaches

An important point to note about the TEV framework is that the *total* economic value from each of the categories of a given ecosystem may not provide much policy-relevant information by itself, since it would be very rare for any action/impact to eliminate an ecosystem entirely. Rather, most policy interest lies in estimating the *change* in TEV between one policy option and another (Pearce and Turner, 1990). Along the same line of reasoning, Barbier et al. (1997) show how the TEV framework can be employed based on a definition of the environmental problem at hand and selection of one (or more) of three broad types of economic evaluation objectives: i) total valuation; ii) partial valuation; and iii) impact analysis.

Total valuation is an assessment of the total net benefits provided to society from a given ecosystem that Barbier et al. (1997) suggest is useful for national income accounting and/or to determine the value of a protected area. For example, an economic valuation of the Laguna de Rocha and its watershed conducted by Gorfinkel et al. (2008) was a pioneering study in Uruguay that used the total valuation approach. *Partial* valuation is the approach most relevant for determining alternative use options of a given ecosystem (Barbier et al., 1997). Given that the lagoon ecosystem has already been designated a protected area and incorporated into Uruguay's National Protected Area System, there does not appear to be much need to value alternative land-use options at this point in time. Finally, impact analysis is an assessment approach used when a disturbance of an ecosystem results in specific impacts to the economic use and/or non-use values of that ecosystem (ibid). Of the three, impact analysis is the most appropriate approach for the purpose of estimating the *impacts* of climate change on the LRPA meanwhile total valuation could provide relevant information to decision-makers in the process of designing the protected area management plan. The theory behind both approaches is described more formally in the following paragraphs.

Climate change Impact Analysis in the Laguna de Rocha Protected Area

For the LRPA, the hypothesis is that climate change impacts observed over the past several decades (Part 1) are having an impact on the economic value of the ecosystem services (Part 2) provided by the coastal lagoon. One of the primary objectives of this study is to estimate whether these climate change impacts are leading to losses or gains (or neither) in lagoon values due to changes in the ecosystem and its resources. From a theoretical perspective using the TEV framework, losses or gains in lagoon values from climate change impacts are the sum of changes in direct, indirect, insurance and existence values due to those climate change impacts, or

$$\Delta_{cc}TEV = \Delta_{cc}Direct + \Delta_{cc}Indirect + \Delta_{cc}Insurance + \Delta_{cc}Existence \quad (1)$$

Total costs of the impacts of climate change on the Laguna de Rocha, TC_{cc}, would then be – ceteris paribus – the change in TEV attributable to climate change, $\Delta_{cc}TEV$.

$$\Delta_{cc}TEV = TC_{cc} \quad (2)$$

Total valuation of the Laguna de Rocha Protected Area

Barbier et al. (1997) argue that one of the main objectives for undertaking the total valuation of an ecosystem is to decide whether or not that ecosystem should become a protected area. Despite the Laguna de Rocha's protected status, local stakeholders are still in the preliminary stages of negotiating its management plan which will be a legally binding document outlining the acceptable uses of the ecosystem and its resources within the area. It may be useful to keep in mind that, from an economic perspective, the LRPA is only worthwhile if the net benefits to society from protecting the area, TEV_{PA}, are greater than: i) the direct costs of its set-up/management, C_{PA}; and ii) the net benefits to society foregone from alternative uses, TEV_{Alt}.

$$TEV_{PA} > C_{PA} + TEV_{Alt} \qquad (3)$$

4.3 Next Steps

While the logic in the above equations is quite straightforward, the methodologies used to arrive at credible monetary values of TEV have been the topic of much debate, revision and refinement. To ‘price’ the many direct, indirect and non-use components of TEV for the LRPA shown in Figure 2, the empirical strategy used by environmental economists has been to develop a variety of monetary valuation methodologies that will be explored in the next section. In practice, the applicability of these techniques is most often limited by data quality/availability as well as time and resource constraints – especially in developing countries (Barbier et al., 1997). Difficult at the best of times, climate change stresses the already-shaky foundation of estimating current and future ecosystem values, particularly due to uncertainty surrounding: i) interdecadal climate variability; ii) climate predictions at regional/local scales; and iii) socio-economic development scenarios (Nakicevonic et al., 2000; Rothman et al., 2003). In order to minimize these considerable uncertainties, the focus of this study is to discuss and apply existing valuation methodologies to the context of estimating non-market costs and benefits of *observed* climate changes in the LRPA. This ‘hind-casting’ approach seeks to: i) provide a base-line for LRPA managers; and ii) discuss the relevance and feasibility of non-market valuation methodologies in the context of climate change impact assessment for future analyses. The next chapter explores the most common methodological approaches to estimating the monetary values of ecosystems in the context of their applicability to the climate change impacts observed in the LRPA.

CHAPTER 5. APPROACHES TO ESTIMATING MONETARY VALUES OF ECOSYSTEM SERVICES IN THE LAGUNA DE ROCHA

5.0 Introduction

This chapter seeks to define the advantages, limitations, relevance and feasibility of specific monetary valuation methodologies for estimating climate change impacts on the ecosystem services of the LRPA. The first section explores the different approaches and methodologies in the environmental economics literature that may be applicable to estimate monetary values of climate change impacts observed in the LRPA. Based on the data needs, advantages and disadvantages discussed for each methodology, the second section analyses the relevance and feasibility of implementing specific monetary valuation methodologies for estimating climate impacts on each of the LRPA ecosystem services. The results of the analysis are used to match three LRPA ecosystem services with relevant/feasible valuation methodologies that will be applied in the next chapter.

5.1 Approaches to Estimate Monetary Values of Ecosystem Services in the Laguna de Rocha Protected Area

When it comes to the monetary valuation of ecosystems, it’s important to note from the beginning that different empirical valuation methodologies are more or less valid theoretically based upon the different measures of welfare calculated for each. Furthermore, as discussed in the previous chapter, there is a heated conceptual debate regarding the economic notion of value as well as the information lost from reducing the multiple uses of ecosystems and the services they provide to a single (monetary) metric (Vatn and Bromley, 1994; Goulder and Kennedy, 1997). The approach taken here is to accept the conceptual arguments for using monetary valuations as one of many indicators of the value of ecosystems to society in order to explore some of their methodological challenges and limitations in developing countries for addressing the newer phenomenon of climate change.

The principal methodologies for monetary valuations can be grouped within four broad approaches for estimating the willingness to pay (WTP) for, or willingness to accept (WTA) the loss of, a given ecosystem component[10]. These are: i) revealed preference methods; ii) stated preference methods; iii) cost-based methods; and iv) rapid assessments. Table 7 outlines the methodologies classified under each approach

[10] Discussions on valuation methodologies can be found in most environmental economics reports and texts. See Teitenberg and Lewis (2010) for an excellent introductory description.

including a short description and the welfare measure used to estimate economic value. The following sections will summarize each methodology and discuss applications, advantages and disadvantages for estimating the monetary value of select ecosystem services vulnerable to climate change impacts in the LRPA. Specific advantages and disadvantages for each methodology are also tabulated in Appendix A

Table 7: Approaches and methodologies for the monetary valuation of ecosystem services

Approach	Methodology	Description	Welfare Measure
Revealed preferences	Productivity Method	Estimates value based on contribution to production of commercially marketed goods	Producer and/or consumer surplus
	Market price method	Assigns value based on total market revenue of goods/services	Total economic surplus
	Hedonic Pricing	Estimates WTP based on price differentials and characteristics of related products	Consumer surplus
	Travel Cost	Estimates WTP based on travel costs incurred to visit	Consumer surplus
Stated preferences	Contingent Valuation	Asks hypothetical questions to obtain WTP or WTA from survey respondents	Consumer surplus (compensating or equivalent variation)
Cost-based	Avoided Cost	Infers WTP from damage costs avoided due to ecosystem good/service	Value larger than damage costs avoided
	Replacement Cost	Infers WTP from costs of replacing ecosystem good/service	Value larger than replacement with an alternative
	Substitute Cost	Infers WTP from value of next best alternative use of resources	Consumer surplus, producer surplus of next best alternative
Rapid Assessments	Benefit Transfer	Transfers the results of previous valuation studies to the ecosystem being studied	Depends on the study

Source: Adapted from Brander (2006)

5.2 Revealed Preferences

Revealed preference methods use market signals and data on observed behaviour to estimate the economic value of ecosystem components (Abeygunawardena, 1999). As such, these methodologies value direct uses and some indirect uses of ecosystem services. This approach is most closely aligned with conventional economic analysis and includes four principal methodologies: i) change in productivity method; ii) market price method; iii) hedonic pricing method; and iv) travel cost method (Pearce and Moran, 1994).

5.2.1 Changes in Productivity Method:

The productivity method estimates ecosystem value as an input to the production of goods commercially sold in markets. The idea is that changes in the quantity or quality of an ecosystem resource used as a factor of production will cause changes in total production costs and/or the productivity of other inputs (Barbier, 1997). Consumer surplus can be estimated if the quality or price of the final product changes. Producer surplus can be estimated if productivity changes (King and Mazzotta, 2000). Advantages are similar to the market price method whereby theoretically sound techniques are used to estimate economic benefits (or losses) from changes in the resource based on observed changes in market data. An additional advantage to the change in productivity method is that un-priced ecosystem service values can be revealed based on their factor 'share' in a production function as long as the ecological-economic relationship is known and output is measured (Pearce and Moran, 1994).

The disadvantages of this method are largely related to difficulties specifying the relationship between environmental changes – climate, in our case – and the productive activity. In particular, the presence of ecosystem tipping points and other non-linear responses to climate changes imply that simple linear relationships may be inadequate (ibid). Furthermore, the productivity method can be complicated to apply if: i) changes in the factors of production change the price of the final good; and ii) no close substitutes exist (King and Mazzotta, 2000). Finally, all of these issues along with assumptions surrounding elasticities of substitution between production factors that determine the functional form of an estimating equation may result in model mis-specification that can bias estimates of welfare changes (van der Werf, 2007).

The productivity method is most relevant in the LRPA for estimating changes in production costs of livestock, agriculture and fisheries caused by changes in soil and water quality due to changes in precipitation patterns, increased extreme weather events and/or rising sea levels. Despite growing tourism potential, economic activity in the protected area remains mostly devoted to the above productive activities so the change in productivity method is arguably the most relevant for valuing climate change impacts. The limiting factor in the LRPA for applying this method was the requirement for local historical production data for each sector that was either non-existent or difficult to collect given time and resource constraints. That being said, the method will be demonstrated in the next chapter with a case study of precipitation changes on the LR shrimp fishery using a (dated) 9-year dataset reported in Santana and Fabiano (1999).

5.2.2 Market Price Method

The market price method is the method that economists are often most comfortable with because it uses conventional economic analysis of prevailing market prices and quantities to estimate the value of changes in quantity or quality of the ecosystem good or service in question (Pearce and Turner, 1990). Data is often relatively easy to acquire even in the generally data-scarce context of developing countries (though it may not be very current). Observed behaviour on people's willingness to pay for the costs and benefits of traded goods implies that their use values are generally well-defined (King and Mazzotta, 2000).

The down-side is that the market price method is only valid for the few ecosystem services that are directly traded in markets. As discussed above, ecosystem services are often 'inputs' to productive activities rather than final outputs traded in markets. Even when traded, market data may not reflect the multiple values of all productive uses of an ecosystem resource (Vatn and Bromley, 1994). Also, the central assumptions of economic theory rarely hold for ecosystems meaning that total economic value will not be reflected in market prices due to market imperfections (externalities) and/or policy failures. Finally, ecosystem benefits will be overstated if the market prices of other inputs used to bring products to market are not deducted (King and Mazzotta, 2000).

Based on the above, the market price method can be particularly relevant for valuing the carbon sequestration service of the LRPA. Since the existence of the carbon market is a direct response to limit climate change caused by CO_2 emissions, the economic value of the carbon sequestered in the soils of the LRPA can arguably be attributed fully to climate change (Kulshrethsha et al., 2000). The method can be applied with data on carbon prices and quantity of carbon sequestered by the LRPA to estimate the demand curve and resulting change in consumer surplus from changes in quantities of carbon stored or price changes in the carbon market. A case study is demonstrated in the next chapter.

5.2.3 Hedonic Pricing

The hedonic pricing method constructs an implicit (surrogate) market for an environmental attribute assuming that prices of a marketed good (typically real estate) reflect various characteristics that include environmental and non-environmental factors (Teitenberg and Lewis, 2010). Deriving surrogate markets are theoretically valid techniques (assuming well-functioning markets) that use observed behaviour to infer WTP for environmental qualities or attributes. For example, property values are related to a number of characteristics including agricultural output, shelter, access to the workplace and also the environmental characteristics of the neighbourhood. Hedonic pricing uses statistical techniques to control for non-environmental factors that affect property values in order to infer people's WTP for an improvement in environmental quality (Pearce and Turner, 1990).

This technique is limited to valuing the WTP for environmental qualities and attributes related to housing markets. In particular, the value of a given environmental attribute will not be reflected in home prices if people are unaware of the benefits it provides to them and their property (King and Mazzotta, 2000). An example could be that sea-side properties are often the most expensive despite predictions of rising sea levels and more extreme events in coastal areas. Most importantly, the method requires a large amount of data on a wide range of properties that includes all of the features that influence the property's value as well as socio-economic data on property buyers. Pearce and Moran (1994) suggest that the hedonic pricing method is of limited value in developing countries due to the large data requirements necessary for reliable estimates of ecosystem value. Sure enough, the data required to undertake the hedonic pricing method was not identified in the fairly rural LRPA so this study determined that the method was not feasibly demonstrable for valuing the impacts of climate change.

5.2.4 Travel Cost Method

The travel cost method (TCM) is used to estimate the economic value of ecosystems that are used for recreation (CBD, 2007). It assumes that people's WTP to travel to visit a given area reflects the use value that people place on that area. This method is well-developed and uses actual behaviour to estimate aggregate demand and the consumer surplus from recreational sites based on the number of trips that people make at different travel prices (King and Mazzotta, 2000). The method assumes that people respond to changes in travel costs the same as they would to changes in market prices. This makes it relatively easy to interpret and explain.

In practice, issues surrounding the opportunity cost of time, alternative sites and socio-economic situation all complicate the application of the travel cost method (Pearce and Turner, 1990). Care must be taken to avoid methodological and sampling issues that can bias results. Importantly, given time constraints and a lack of historical visitor data, it was not evident how the changes in resource conditions from climate change impacts in the LRPA could be disentangled from the overall recreational value measured by this method. As a result, it was determined that the travel cost method could be relevant for estimating climate change impacts on the recreational value of the protected area, however, it was not feasibly applied in this study. An application of the TCM that was beyond the scope of this study since it is unrelated to climate change – but probably very useful to LRPA managers – would be to estimate the demand for recreation in the protected area to inform the choice of an acceptable admission price (if any).

5.3 Stated Preferences

The stated preference approach uses surveys to ask people directly how much they would *hypothetically* be willing to pay for, or willing to accept for the loss of, a given ecosystem component. It is widely used as the *only* way to place a (hypothetical) monetary value on non-consumptive preferences for ecosystem components. Stated preferences are considered less reliable than revealed preferences because they are based on what people say they would pay, rather than actual (observed) behaviour. The only stated preference methodology described in this report is contingent valuation[11].

5.3.1 Contingent Valuation Method

Despite nearly 25 years of debate, contingent valuations (CV) remain the most controversial of the monetary valuation methodologies used to estimate the economic value of ecosystems (Smith, 2008). Survey respondents are asked how much they would be willing to pay (WTP) for (or willing to accept the loss of (WTA)) an ecosystem good, function or attribute. It is the most widely accepted method for estimating non-use values of total economic value (Pearce and Moran, 1994). The greatest benefit of the CV

[11] 'Contingent choice' is another survey-based method very similar to contingent valuation in application. The main difference is in the survey design where respondents are not directly asked for their WTP or WTA. Instead, they are asked to make hypothetical trade-offs between different scenarios (with different costs) and then WTP or WTA is inferred from the scenarios chosen.

method is that it can technically be applied to estimate use and non-use values in any ecosystem and environmental context (King and Mazzotta, 2000). The literature on the CV method is substantial and guidelines exist for the 'proper' design of CV surveys (Arrow et al., 1993). Researchers seek the personal valuations of increases or decreases in the quantity of a given environmental attribute contingent upon the institutional context and payment vehicle of a hypothetical market. Respondents say what they would be WTP or WTA for an environmental good or service *if* a market actually existed (Pearce and Turner, 1990). Note that the WTA estimate is the technically correct measure in the LRPA considering: i) Uruguayans have contributed negligibly to global climate change; ii) adaptation costs are defensive expenditures; and iii) there is an observed disparity between WTP and WTA estimates that is not fully explained by economic theory (Pearce and Turner, 1990).

The disadvantages of the CV method stem from the fact that it is based on stated preferences rather than observed or actual behaviour. A host of response biases that can skew the results have been identified by researchers (Knetsch, 1994). As a result, 'proper' CV studies are expensive and time-consuming in survey design/pre-testing and great care must be taken to ensure that survey questions clearly define the environmental service(s) to be valued as well as the specific context and hypothetical scenario (King and Mazzotta, 2000). Applications of the CV method to value future climate change impacts in the LRPA could be to estimate Uruguayan WTP for specific adaptation measures to climate change *or* WTA compensation for the loss of specific environmental services due to climate change. The CV method was not implemented in this study for two reasons. First, the scope here is limited to valuing historical climate changes so the valuation question was not evident (e.g. no need to construct hypothetical markets for something that has already happened). Second, even if estimating the value of future impacts of climate change fell within the scope of this study, the design and implementation of a CV survey according to rigorous international standards were limited by the time and resource constraints of the one-year research award that provided the basis for this thesis.

5.4 Cost-based Methods

The broadly related cost-based methods assume that useful values can be inferred from the additional costs incurred from either avoiding damages due to lost ecosystem functions, replacing environmental assets or providing substitute services (King and

Mazzotta, 2000). This assumption may or may not be true since it is well-accepted that costs are often not an accurate measure of benefits (Barbier, 1997). The principal methodologies are: i) damage cost avoided; ii) replacement cost; and iii) substitute cost. These methods do not estimate demand curves and therefore do not provide theoretically valid measures of value based on people's WTP for the benefits and costs of a given good or service. However, for discussions surrounding the costs of adaptation to climate change, it could be argued that measures of economic costs may be all that is required. In any case, given data- and resource-constrained contexts, cost-based methods can provide a rough indicator of economic value when valuation methods of WTP (or WTA) are not feasible.

5.4.1 Damage Cost Avoided

The damage cost avoided method estimates the value of ecosystem services based on the damage costs avoided by investing in ecosystem protection. This method is relatively straight-forward to implement and provides a rough indicator of economic value for services that are otherwise difficult to value (King and Mazzotta, 2000). It is particularly relevant for estimating the impacts of climate change on the 'habitat maintenance' and 'cultural' ecosystem services identified in Table 6. For example, by analyzing the costs incurred to protect the LRPA with and without climate change, the damage costs avoided method assumes that the value of climate change impacts to these LRPA ecosystem services must be *at least* the additional costs that people incur to adapt to a changing climate.

The disadvantage here is that economic value, based on WTP for the costs *and benefits* of damage costs avoided, is not estimated. Preferences and individual behaviour (e.g. demand) for ecosystem services are not considered. However, for ecosystem services that have no market data, the damage cost avoided method can be relevant and feasible for inferring a rough value of climate change impacts as long as people are incurring costs to avoid damages. A case study of the example from the previous paragraph will be demonstrated in the next chapter.

5.4.2 Replacement Cost

The replacement cost method estimates the value of ecosystem services based on the costs incurred to replace that ecosystem service (Barbier, 2007). For example, the installation costs of a water treatment plant can be used as the replacement costs of water purification services provided by draining wetlands. In fact, Gorfinkiel et al. (2008) use the replacement cost method to value the water treatment services of the riparian forest between Rocha City and the Laguna de Rocha by analyzing the costs of upgrading and maintaining the existing treatment facility. For the case of valuing climate impacts on water treatment, it is felt that the production function method described above can also be feasibly applied to provide a more theoretically valid value for changes in pollution control.

Other ecosystem functions relevant to climate change impacts in the RLPA and popularly valued using the replacement cost method include: i) sediment retention; ii) storm buffering; and iii) carbon sequestration (Brander, 2006). Like the damage costs avoided method, replacement cost is relatively straight-forward to implement and provides a rough indicator of economic value for services that are otherwise difficult to value. It is particularly relevant for specific ecosystem services for which technical alternatives exist. An important assumption is that the human-made alternative is an acceptable replacement for a given ecosystem service loss. In practice, very few environmental resources have perfect substitutes.

5.4.3 Substitute Cost

The substitute cost method estimates the value of ecosystem services based on the costs of the next-best alternative for a particular ecosystem service. In practice, it is very similar to the replacement cost method except that it requires an estimate of the degree of substitutability between the ecosystem service and 'next-best' alternatives (rather than assuming that perfect substitutes exist) (King and Mazzotta, 2000). Construction of retaining walls or levees to protect against floods is often an example of substitute costs. An issue with this method is that it assumes that the cost of the next-best alternative to an ecosystem service is a valid estimate of economic value without considering people's preferences for the ecosystem service itself. As a result, some evidence that society would demand the ecosystem service being substituted by the next-best alternative should be provided (Barbier, 2007).

5.5 Benefit Transfer

The benefit transfer method is not a valuation approach in its own right. Rather, it is a method used to transfer the monetary valuation results of another valuation study from one specific ecosystem context to another usually due to a lack of data, time and/or resources (King and Mazzotta, 2000). At best, results from the benefit transfer method can only be as good as the results of the initial study. At worst, benefit transfer may not be even remotely accurate because of differences in site characteristics and context. Good quality studies may not be available for the relevant issue/context. The method is more popular in developing countries where data, time and financial resources are typically more constrained (Abeygunawardena, 1999). King and Mazzotta (2000) suggest that benefit transfer can be used as a screening method to decide whether a more comprehensive valuation study is required. Technically, it can be applied under any circumstance as long as previous studies exist. The relevance of benefit transfer to estimating costs of climate change impacts in the LRPA depends on the identification of quality studies that value comparable ecosystems with similar characteristics.

5.6 Relevance and Feasibility of Valuation Methodologies for Estimating Climate Impacts in the Laguna de Rocha

Table 8 summarizes the relevance and feasibility of each of the monetary valuation methods discussed in this chapter with each of the ecosystem services identified in Chapter 3. Many of the principal environmental economic valuation methodologies are relevant for valuing climate change impacts on specific ecosystem services of the Laguna de Rocha Protected Area. Some methodologies are more feasible than others, particularly those classified under the cost-based approach. It is clear that they all have advantages and disadvantages when it comes to estimating the monetary values (or costs) of climate change impacts (see Appendix A).

Table 8 – Relative relevance and feasibility of valuation methodologies for estimating the economic impact of climate change on ecosystem services vulnerable to observed climate changes in the LRPA

R: Relevance; F: Feasibility. Scale is low R; F, medium R; F to high R; F. Blank cells indicate that the monetary valuation methodology is considered both low relevance and feasibility for the ecosystem service

Ecosystem services	LRPA Item	Market price	Change in Production	Hedonic pricing	Travel Cost	Contingent valuation	Damage costs avoided	Replacement cost	Substitute cost
Provisioning									
Food	Commercial fish and crustaceans	R;F	R;F			R;F	R;F	R;F	R;F
Fuel & fibre	Natural grasslands & prairies	R;F	R;F			R;F	R;F	R;F	R;F
Regulating									
Flood & storm protection	Dunes; LR water body		R;F	R;F		R;F	R;F	R;F	R;F
Pollution control	Emergent plants; Riparian forest*		R;F	R;F		R;F	R;F	R;F	R;F
Erosion control	Dunes; Emergent plants		R;F	R;F		R;F	R;F	R;F	R;F
Carbon sequestration	Emergent wetland plants	R;F				R;F		R;F	R;F
Habitat									
Maintenance of life cycles	Migratory birds; Resident species					R;F	R;F	R;F	R;F
Cultural									
Recreational	Tourism	R;F	R;F		R;F	R;F			
Educational	Formal & informal education/training					R;F	R;F		
Aesthetic	LRPA			R;F	R;F	R;F	R;F		
Spiritual & Inspirational	LRPA; fishing communities				R;F	R;F	R;F		

LR: Laguna de Rocha; (*) not included in the currently delimitated protected area. **Sources:** Author's opinion based on references cited in the main text. Typology adapted from MEA (2005) and de Groot et al. (2010).

Methodologies under the revealed preference approach are the least controversial means of estimating economic value. In the context of climate change impacts, the 'change in production' method is highly relevant for estimating the economic value of changes in climate 'inputs' to the main productive activities in the LRPA (e.g. livestock-raising, agriculture and fisheries). The feasibility of this approach is dependent on: i) correctly specifying the ecological-economic relationship; and ii) historical time series data availability that was difficult (but not impossible) to identify and access depending on the ecosystem service. The market price method is arguably most relevant and feasible for estimating the value of carbon sequestration in the protected area if the existence of the carbon market is considered a direct 'impact' of climate change. Hedonic pricing is highly relevant for valuing changes in the aesthetic ecosystem service but was found to have low feasibility for application in the LRPA. The travel cost method is highly relevant for valuing changes in recreational use due to climate change impacts however the timing of this study did not coincide with the summer tourist season when the LRPA receives the majority of its visitors.

The stated preference approach is a highly relevant and flexible way to estimate internally consistent measures of economic value for ecosystem components not related to any markets. However, the application of the results of contingent valuations to real-life situations is controversial. As well, survey design/implementation is less feasible because of high costs in meeting the rigorous standards of the profession.

Cost-based methodologies are not as highly relevant because they do not estimate economic value but rather assume that useful values can be inferred from the additional costs incurred from avoiding damages due to lost ecosystem functions, replacing environmental assets or providing substitute services. That being said, these methodologies do not consider social preferences for ecosystem services. Similarly, they do not consider individual behaviour in the absence of those services. These methodologies are often more feasibly applied than revealed or stated preference methodologies and are arguably more relevant to debates surrounding financial mechanisms for the *costs* of adaptation. Finally, benefit cost method (not shown in Table 8) is a cost-effective means to provide general estimates of economic value as long as good quality studies exist for the type of ecosystem service being valued in a similar context.

While none of the valuation methodologies satisfactorily capture the total economic value of a given ecosystem, it seems clear that each could provide a useful indicator, depending on information and data availability, to accompany other social and biophysical indicators used to inform decision-making. The next chapter will present three case studies from the LRPA of the most relevant and feasible monetary valuation methodologies identified in Table 8.

CHAPTER 6: LAGUNA DE ROCHA CASE STUDIES

6.0 Introduction

The objective of this chapter is to use the information gathered thus far to estimate monetary values for select ecosystem services in the Laguna de Rocha Protected Area. A variety of the monetary valuation methodologies explored in the previous section will be implemented and the results will be discussed critically. The feasibility of the following valuation methodologies to estimate the local impacts of climate change in the Laguna de Rocha will be tested. First, the impact of rainfall changes on production will be estimated using a production function method for the shrimp fishery. Next, the value of carbon sequestration by emergent wetland plants in the lagoon will be estimated using the market price method from the carbon market. Third, investments in habitat maintenance and research will be used to value the damage costs avoided by maintaining the ecosystem and increasing knowledge. The final section will conclude with a discussion of other valuation methodologies that would be particularly relevant to estimating the impact of climate change on ecosystem services of the lagoon but, for various reasons, were not feasibly implemented in this study.

6.1 Production Function Approach: Climate as an 'Input' to Production

In the context of climate change, it is argued that the production function (PF) approach is the most relevant methodology to estimate the economic value of non-market changes in climate factors that impact economically productive activities (Barbier, 2007; Table 8). As discussed in the previous chapter, the impact of climate change on a number of productive activities in the protected area could be estimated using this approach including: i) fisheries; ii) livestock and agriculture; and iii) water treatment upstream. This study uses the example of shrimp fishing in the lagoon to demonstrate, with relatively small data requirements, the feasibility of implementing the PF approach to value local changes in climate on productive activities of the protected area.

More specifically, a habitat-fishery linkages model is adapted to the context of shrimp fishing in a changing climate in the Laguna de Rocha. A number of researchers have successfully implemented the PF approach to value the 'indirect' breeding/nursery function of wetland areas as inputs to near-shore fisheries production in diverse settings from Chesapeake Bay to Southern Thailand[12]. The novel aspect of using the PF approach for this study is to argue that climate, especially precipitation, also provides an indirect regulating 'service' that influences the capture of shrimp (and other economically productive activities) in the Laguna de Rocha. As a result, a change in climate could be expected to change the quantity of shrimp caught.

Barbier (1994) outlines a two-step procedure for implementing the production function approach for valuing an ecosystem service:

i) The physical effects of changes in a biological resource or ecological service on an economic activity must be determined; and
ii) The impact of these environmental changes must be valued in terms of the corresponding change in marketed output of the relevant activity.

For the first step, the physical effects of observed changes in climate on shrimp capture (or beef production, or whatever) are difficult to measure directly, as is the case for most ecosystem services. In practice, since data on physical and ecological pathways are often not available, the standard tactic of the PF models in the literature is to use a proxy for the physical share in production allocated to the ecosystem service (Barbier, 2000)[13].

For our purposes of estimating climate change impacts on shrimp fishing, average annual rainfall of the year preceding harvest was chosen to be a proxy for the physical impact of climate changes. This is a considerable simplification because, as seen in Section 3.1.1, winds, wave action and continental run-off also contribute significantly to the hydrological regime of the lagoon that determines the conditions for shrimp production. For future estimations, an integrated index would be preferable, but data and resource constraints limited the scope of this study to using only accumulated rainfall as the proxy for ecological conditions. The next step consists of linking the changes in average rainfall amounts to changes in market quantities/prices for shrimp in the protected area and ultimately to consumer and producer surpluses. While the general approach is the same for treating changes in rainfall (or any other ecosystem service) as input to a productive activity, the following sub-sections describe the application of the 2-

[12] For empirical examples of the habitat-fishery production function approach to valuation, see Lynne et al. (1981), Ellis and Fisher (1987), Freeman (1991), Sathirathai (1997), Barbier and Strand (1998)and Barbier (2003; 2007)
[13] Wetland area is the standard proxy in habitat-fishery models in the literature

step procedure outlined above to estimate precipitation-shrimp linkages in the Laguna de Rocha.

6.1.1 Precipitation-Shrimp Linkages in the Laguna de Rocha

Shrimp fishing in the Laguna de Rocha generally begins at the end of austral summer (end of February) and runs until the end of autumn (sometime in May) (Norbis, 2000). The target species is juvenile Sao Paulo Shrimp (*Penaeus Paulensis*) that, dependent upon environmental conditions, enter the lagoon in a post-larval phase to mature in an area relatively free of predators before migrating back to sea to reproduce as adults (ibid). Assuming that the post-larval shrimp are present in Uruguay's coastal waters, at least two hydrological conditions must take place in the dynamic lagoon ecosystem for the Sao Paulo shrimp to thrive. The first is that the sandbar is open to the ocean during austral spring so that the post-larval shrimp are able to enter the lagoon (Santana and Fabiano, 1999). As shown in Figure 13, rainfall and continental run-off play an important role on the dynamics of the sandbar. The second condition is that, while the juvenile shrimp can tolerate changes in salinity, they prefer salty water as an estuarine/marine species (Norbis, 2000). In particular, the salinity of the shallow lagoon is sensitive to changes in rainfall/run-off (Bonilla et al., 2006). As such, we could hypothesize a negative relationship between shrimp harvests and rainfall accumulated the previous year of harvest (as long as the sandbar was open to let the post-larval shrimp into the lagoon). Having hypothesized the physical effects of a change in rainfall amounts on shrimp harvests, the following paragraphs will describe the one-period model more formally assuming open access conditions in the Laguna de Rocha shrimp fishery.

6.1.2 Production Function Model of Precipitation-Shrimp Linkages

The 'static' one-period model adapted from Barbier (2007) described below can be used to value how a change in precipitation affects the harvest, prices and consumer surplus of the open-access Sao Paulo shrimp market in the Laguna de Rocha. A static model was chosen for two reasons. The first is a serious deficit in information needed to model the 'dynamic' intertemporal effects of precipitation changes on Sao Paulo shrimp stocks. Despite their economic importance, very little is known about the adult population characteristics of the shrimp found in coastal waters from Cabo Frío, Brazil (23'00''S) to the northern coast of Buenos Aires province, Argentina (38'30''S) (Norbis, 2000). Secondly, given the lack of a local breeding stock and large distribution of the species, it is assumed that the relatively small scale of the Laguna de Rocha harvest does not significantly impact the shrimp stock in which case a static model was considered sufficient, at least for this first estimate. Finally, the management of the lagoon shrimp fishery is considered open access meaning that any profits will attract new fishers until all profits disappear and, following Freeman (1991), the welfare change in the environmental service will impact consumer surplus only. Alternatively, the static approach has also been used to model the fishery under optimally managed conditions (see Sathirathai and Barbier, (2001)) however it was felt that an open access management regime better reflects the reality of the shrimp fishery in the LRPA.

More formally, adapting the model in Barbier (2007), let the production function of the marketed Sao Paulo shrimp harvest be:

$$h_t = h(E_i \ldots E_k, R_{t-1}) \qquad (4)$$

Where h is the marketed harvest of shrimp and R is the average annual rainfall of the preceding year that could directly impact the harvest independent from the conventional shrimp fishing inputs, $E_i \ldots E_k$.

A standard, and important, assumption in the literature on static habitat-fishery models, is to assume that the production function (4) takes the Cobb-Douglas form, $h = AE^aR^b$, where E is an aggregate of total fishing effort and R is average annual rainfall. Using the Cobb-Douglas functional form, one can employ standard neo-classical profit-maximizing harvesting behaviour to the Laguna de Rocha fishers yielding the optimal cost function:

$$C^* = C(h, w, R) = wA^{-1/a}h^{1/a}R^{-b/a} \qquad (5)$$

Where w is the unit cost of effort, A is a measure of total factor productivity, and a and b are output elasticity parameters. Following Barbier (2007), the demand function is assumed to be iso-elastic, $P = p(h) = kh^{\eta}$, $\eta = 1/\varepsilon < 0$, and the market equilibrium for catch in the open access shrimp fishery occurs when total revenues of the fishery just equal cost, or price equals average cost[14], e.g. $P = C^*/h$, or:

$$kh^{\eta} = wA^{-1/a}h^{(1-a)/a}R^{-b/a} \qquad (6)$$

[14] An optimally managed fishery can also be modeled using marginal costs instead of average costs

that can be rearranged to solve for the equilibrium level of shrimp harvest:

$$h = \left[\frac{w}{k}\right]^{a/\beta} A^{-1/\beta} R^{-b/\beta},\ \beta = (1 + \eta)a - 1 \tag{7}$$

Taking the derivative of harvest with respect to precipitation in (7) yields the marginal impact of a change in precipitation:

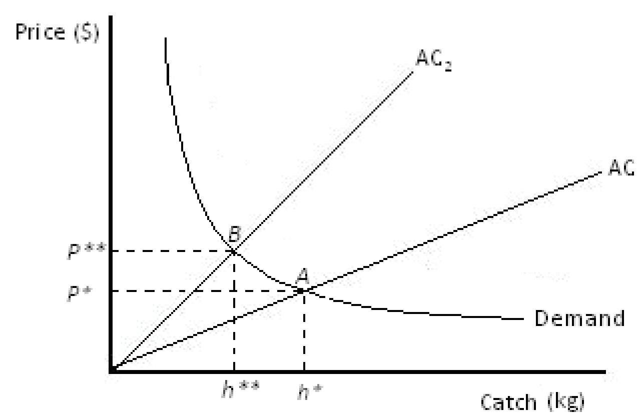
$$\frac{\partial h}{\partial R} = -\frac{b}{\beta}\left[\frac{w}{k}\right]^{a/\beta} A^{-1/\beta} R^{-(b+\beta)/\beta} \tag{8}$$

Finally, the change in consumer surplus, CS, caused by a change in equilibrium harvest levels (from h^0 to h^1) is given by integrating and rearranging to:

$$\Delta CS = -\frac{\eta[p^1h^1 - p^0h^0]}{\eta+1} \tag{9}$$

Equations (8) and (9) allow us to estimate the new equilibrium harvest, price levels and corresponding changes in consumer surplus, for a given demand elasticity (Barbier, 2003; 2007). Figure 17 is a stylized diagram of the welfare impact of a change in rainfall accumulation on the Sao Paulo shrimp fishery. The diagram shows that a change in precipitation that impacts the hydrological conditions of the lagoon causes a shift in the average cost curve, AC, of the open-access shrimp fishery. The resulting welfare impact is the change in consumer surplus area, P*ABP** (Freeman, 1991; Barbier, 2007).

Figure 17 – Economic value effects of increased precipitation on the Laguna de Rocha shrimp fishery



AC: Average cost; P: price per kg; h: shrimp catch; (*) before change; (**) after change; Decrease in consumer surplus after change: Area P*ABP**. **Source:** Adapted from Barbier (2007).

6.1.3 Valuation of Precipitation as an Input to Shrimp Production

To conduct the static production function analysis of precipitation-shrimp linkages for the Laguna de Rocha, the methodology described above is applied to shrimp capture and effort in the lagoon and average annual precipitation data for Rocha from 1991 to 1999.

The shrimp capture and effort data were the limiting factors in the analysis because of: i) resource constraints with respect to the collection of primary data; and ii) fishing in coastal lagoons is considered ‘terrestrial’ so there is minimal regulation or registration of secondary data by the Uruguayan authorities (Norbis, pers. comm., Aug. 18, 2011). The estimates of harvest/effort over the 9-year period were conducted by Uruguay’s *Instituto Nacional de Pesca* (INAPE, National Fisheries Institute) as reported in Santana and Fabiano (1999). Harvest is estimated in kilograms of shrimp per season while the only time-series estimate of effort available was number of shrimp fishers. As a result, a strong assumption had to be made that all fishers use the same number of traps and work the same number of hours per season. Precipitation data were obtained from Uruguay’s *Dirección Nacional de Meteorología* (DNM, National Meteorology Authority).

To calculate the change in equilibrium harvest in equation (4) and marginal impact of a change in precipitation in equation (5), the unknown parameters (A, a and b) of the Cobb-Douglas production function for the fishery were estimated using the log-linear specification of the model:

$$\ln h_t = A_0 + a \ln E_t + b \ln R_{t-1} + \varepsilon_t \quad (10)$$

Where $t = 1,\ldots,9$ years (1991-1999) and $A_0 = \ln A$.

6.1.4 Results

The log-linear model was estimated utilizing and comparing both generalized least squares (GLS) and ordinary least squares (OLS) regression procedures under various error structures for two groups of observations. Table 9 reports summary statistics and the results of both procedures for both samples. The first group uses all of the observations available whereas the second excludes an outlier of harvest/effort in 1997 far above the norm for the lagoon (see Table 9 summary statistics). The GLS regression for fitting panel data with a heteroskedastic error structure provided the best regression model yielding coefficients with the expected signs for both groups though A_0 and *b* are only significant for Group 2. The results of the preferred GLS model for Group 2 from Table 9 were then used in equation (4) to compute the equilibrium harvest levels and equilibrium prices arising from the increase in rainfall.

Table 9 – Summary statistics and estimates of equation (10) for LR shrimp fishery

Summary Statistics							
	Group (1)	**Group (2)**					
# Obs.	9	8					
			Mean ($\bar{x}$)		**Std. Dev. (σ)**		**Corr w/ harvest (ρ)**
Variables		(1)	(2)	(1)	(2)	(1)	(2)
Harvest (kg)		10,859	2,716	24,598	3,088	1.00	1.00
Effort (# of fishers)		47	16	96	12	0.99	0.95
$Rainfall_{t-1}$ (mm)		1,149	1,177	151	133	-0.59	-0.35

Estimates of equation (10) for Laguna de Rocha shrimp fishery				
	Group 1		**Group 2**	
Coefficients	OLS	GLS	OLS	GLS[a]
A_0	-3.760 (-0.07)	4.666 (0.15)	15.724 (1.29)	18.494 (2.09)*
a	2.171 (4.10)**	2.363 (8.42)**	2.509 (15.12)**	2.428 (21.00)**
b	0.663 (0.11)	-0.577 (-0.13)	-2.164 (-1.29)	-2.533 (-2.09)*
R^2	0.93	-	0.99	-
s.e.e.	1.21	-	0.46	-
Wald test[b]	-	128.58**	-	3047.74**

Notes: t-statistics are shown in parentheses; * significant at 95% confidence level; ** significant at 99% confidence level
[a]Preferred model is groupwise heteroskedastic cross sectional time series generalized least squares (GLS)
[b] Tests the null hypothesis of homoscedasticity based on OLS
Source: Author's estimations

The statistically significant values for k and η in the iso-elastic demand function were estimated from price and harvest data between 1991-1998 using OLS. Table 10 reports the equilibrium prices, harvests and resulting welfare loss calculated from the 195.5 mm increase in rainfall observed from 1961 to 1998 in the Laguna de Rocha shrimp fishery. The ranges of values indicated in parentheses are the 95% confidence bounds from the standard errors of the estimated parameters.

Table 10 – Equilibrium prices, quantities and valuation of rainfall-shrimp linkage in the Laguna de Rocha (Uruguay), 1961-1998

		After increase of 195.5 mm (1998)		Before increase of 195.5 mm (1961)	
Elasticity	Demand function	P_1 (US\$/kg)	h_1 (kg)	P_0 (US\$/kg)	h_0(kg)
$\eta = -0.2$	$P = 43.05h^{-0.2}$	10.38	1,225	9.52	1,887

Value of rainfall as input to the Laguna de Rocha shrimp fishery (as measured by change in net welfare)	
Total welfare loss (US$)	Welfare loss per mm of rainfall (US$)
1335 (258 – 234,732)	**6.83** (1.32 – 1,200.68)

Notes: Rainfall increase calculated as a linear trend from the *Dirección Nacional de Meteorología* rainfall data for Rocha from 1961-1998. Figures in parentheses represent upper and lower bound welfare estimates based on the standard error of the estimated parameters. **Source:** Author's calculations

Table 10 shows that the total welfare loss to the flow of shrimp capture in the Laguna de Rocha due to the linear increase in rainfall observed between 1961 and 1998 were US $1,335 ($258 to 234,732 with 95% confidence) or US $6.83/mm ($1.32 to 1,200.68 with 95% confidence). In this particular case study, the model suggests that increases in average rainfall have had a significant negative impact on the welfare of shrimp fishers in the Laguna de Rocha. That being said, the confidence bounds surrounding this point estimate are quite large suggesting caution interpreting these results for policy analysis. However, the point estimate is on the low end of the estimated range suggesting that the model generates a conservative estimate. Future research could likely improve the results by incorporating a 'dynamic' approach that models the impact of precipitation on shrimp stocks over time[15].

In sum, this case study of the Laguna de Rocha shrimp fishery has demonstrated the feasibility and relevance of the PF method to estimate the local economic welfare impacts of climate change in a developing country context. A static one-period model was developed to model precipitation-shrimp linkages in the LRPA using a Cobb-Douglas functional form. While the Cobb-Douglas form chosen is useful for demonstration purposes, the rigid assumptions implicit in the model, particularly of unitary elasticity of substitution, have been criticized as overly simplistic (van der Werf, 2007; Kummel et al., 2010).

After testing various regression procedures on two groups of observations, the preferred model yielding statistically significant coefficients with the expected signs was groupwise heteroskedastic generalized least squares (GLS). A major advantage of this quantitative method is that the standard errors of the coefficients permit the estimation of upper and lower bound welfare estimates as indicators of uncertainty around the point estimates. For the case of the LRPA, while the point estimate values of precipitation impacts on the shrimp fishery were reasonable given the small size of the fishery (US $1,335), the range of welfare values estimated at 95% confidence was very large (US $258 – 234,732). This large range could be related to the considerable variability among the small number of observations in the 8-year dataset. Another cause could be the 'static' approach modelled that Barbier (2007) suggests has a larger degree of uncertainty than dynamic analyses that incorporate changes in the stocks of the target species.

[15] See Barbier (2007) for a comparison of static and dynamic approaches to valuing mangrove-fishery linkages

Notwithstanding the limitations of the above model, it is hoped that the results of this case study using the production function approach to value rainfall impacts on a developing country fishery can contribute to the discussion on the non-market valuation of climate change literature.

6.2 Market Price Approach: Carbon Sequestration of Emergent Wetland Plants

In order to value the impact of climate change on carbon sequestration in the Laguna de Rocha, it is argued here that the market price method is now the most appropriate method for monetary valuation, given the consolidation of the carbon market over the past decade. Wetlands are widely recognized for their global importance as carbon sinks occupying only 4-6% of the planet's surface yet storing 20-25% of the world's soil carbon (Sampson et al., 2000). Coastal wetlands are particularly important for mitigation of GHG emissions because, unlike freshwater wetlands, they sequester carbon without emitting significant amounts of methane (Magenheiner et al., 1996; Choi and Wang, 2004). As such, while there is a lack of quantitative valuation studies (Engle, 2011), researchers note that coastal wetlands could be more valuable carbon sinks per unit area than many other ecosystems in a warming world (Choi and Wang, 2004). In fact, one could argue that carbon sequestration only acquired an economic value as potential damages of global climate change from anthropogenic GHG emissions have become more evident (Kulshreshtha et al., 2000).

A two-step process is envisaged to determining a monetary value for carbon sequestered in the Laguna de Rocha (Kulshreshtha et al., 2000).

i.) Estimate of the physical quantity of carbon being stored by the lagoon ecosystem; and

ii.) Changes in market prices of carbon (or emissions reductions credits demanded) give an idea of the sequestration value of carbon at a given point in time.

Note that a significant simplification implicit in this two-step methodology is the assumption that the carbon stored by the Laguna de Rocha can be traded in the carbon market with zero transaction costs. In reality, there are a number of steps, regulations and certifications required before Uruguay could be eligible to receive credit for any emissions reductions under the "Flexible Mechanisms" of the Kyoto Protocol that occur, for example, from the designation of the lagoon ecosystem as a protected area

(UNFCCC, 2005). As such, the results of this estimation should be seen as a demonstration of the methodology and perhaps a first indication of whether pursuing emissions reduction credits from protecting coastal lagoons merit further research.

6.2.1 Estimating Carbon Stored by Laguna de Rocha Wetland Soils

Specific soil carbon densities and accumulation rates for the Laguna de Rocha could not be found through consultation with local experts and presumably do not exist. As such, an average accumulation rate of 174 g $m^{-2}yr^{-1}$ was calculated from 12 sites in the USA with fairly similar climatic regimes (± 1.9°C average annual temperature) found in the 154-site sample of tidal saline wetlands compiled by Chmura et al. (2003). The locations, accumulation rates and average annual temperatures of the selected sites are shown with the Laguna de Rocha information in Table 11

Table 11 – Site Locations, average annual temperature and carbon accumulation rates

Site Location	Latitude	Longitude (°W)	Avg. Temp. (°C)	Accumulation Rate (g $m^{-2}yr^{-1}$)
Laguna de Rocha, Rocha, UY	34.4°S	54.3	16.3	--
Tijuana Slough, California, USA	32.5°N	117.1	17.6	343
Tijuana Slough, California, USA	32.5°N	117.1	17.6	43
Alviso, California, USA	37.5°N	122.0	15.5	385
Bird Island, California, USA	37.6°N	122.2	15.5	54
Cedar Island, N. Carolina, USA	35.0°N	76.4	17.0	70
Oregon Inlet, N. Carolina, USA	35.9°N	75.6	16.6	59
Oregon Inlet, N. Carolina, USA	35.9°N	75.6	16.6	21
Jacob's Creek, N. Carolina, USA	35.3°N	76.8	16.6	146
Jacob's Creek, N. Carolina, USA	35.3°N	76.8	16.6	107
MC4, Chesapeake Bay, Md., USA	38.3°N	75.9	14.4	308
MCL8, Chesapeake Bay, Md., USA	38.3°N	75.9	14.4	213
MCL15, Chesapeake Bay, Md., USA	38.3°N	75.9	14.4	340
			AVERAGE	**174**

Avg. Temp: Average annual temperature. **Source:** Adapted from Chmura et al. (2003)

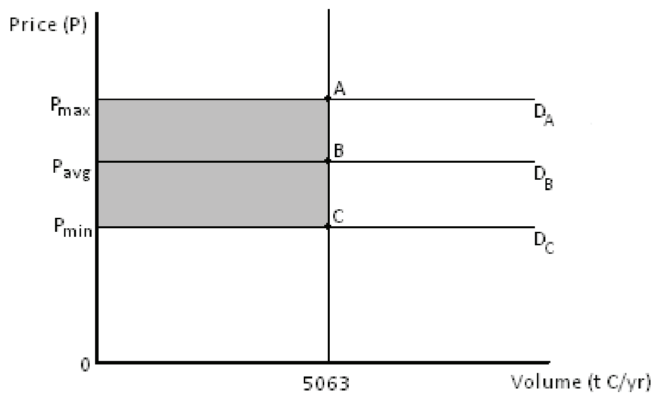
By converting the average carbon accumulation rate in wetland soils from annual grams per square meter (g m^{-2} $yr^{-}1$) to annual metric tons per hectare (t ha^{-1} yr^{-1}) and multiplying by the area (ha) in the 'emergent wetland plants' and 'lagoon inlets' zones from Table 5, the proxy estimate of total annual carbon stored by Laguna de Rocha wetlands is:

$$\text{LR Annual carbon (C) stored} = 1.74 \text{ t C ha}^{-1}\text{ yr}^{-1} * 2910 \text{ ha} = \mathbf{5063.4 \text{ t C yr}^{-1}} \quad (11)$$

6.2.2 Estimating the Market Value for Laguna de Rocha Carbon Sequestration

Carbon market data were obtained on the daily trade of Certified Emission Reductions (CERs) generated from projects under the Clean Development Mechanism (CDM) of the Kyoto Protocol between 2008 and 2011[16]. Given the large volumes of carbon traded on the global CER carbon market (e.g. more than 46 million tons of carbon in 2010) relative to the Laguna de Rocha 'supply', the market demand curve was found to be essentially flat at the scale of changes in the coastal lagoon carbon sequestration volume. On the other hand, changes in total carbon volume explain next to none of the volatility in prices using linear and iso-elastic demand estimations (R^2= 0.009 and 0.014, respectively). This demonstrates that exogenous factors other than supply play the dominant role in determining prices and demand for carbon.

Figure 18 –Market for Laguna de Rocha carbon



Market demand for carbon shifts due to external price shocks (Pmax; Pavg; Pmin) but is unaffected by changes in the small volume of carbon supplied by the Laguna de Rocha to the global carbon market. Change in total (potential) revenue between Pmax and Pmin from price volatility is shown in grey.

As Figure 18 shows, the effects of exogenous price changes on Laguna de Rocha carbon sequestration have no impact on total consumer surplus assuming that: i) the addition (or subtraction) of total Laguna de Rocha carbon sequestration volume has no impact on global carbon demand; and ii) we are assuming a fixed supply of carbon accumulation in the Laguna de Rocha. As a result, it's argued that the most relevant monetary estimate for the *local* carbon sequestration service is a financial assessment of the change in potential annual revenue flows in the lagoon due to exogenous price shocks.

[16] Carbon market data was accessed on 26 October, 2011 from the BlueNext website (URL: http://www.bluenext.eu/statistics/downloads.php)

6.2.3 Results

Table 12 presents the results of the financial assessment used to calculate average annual revenue (in current euros) from carbon sequestration in the Laguna de Rocha using 2008-2011 prices for CERs. Note that the molecular weight of CO_2 is 44 while the atomic weight of carbon alone is 12, so the sequestration of 1t C is equivalent to having pulled 3.67t CO_2 from the atmosphere (e.g. 3.67t CO_2 = 1t C * (44 CO_2/12 C).

Table 12 – Annual revenue potential from Laguna de Rocha carbon sequestration service

Year	Volume (tC/yr)	Price (€/tCO_2e)			Annual revenue in current euros (€)		
		Min	Avg	Max	Min	Max	Change
2008	5063.4	12.83	16.84	20.65	238416	383732	145317
2009	5063.4	7.6	11.91	13.9	141228	258299	117071
2010	5063.4	10.97	12.53	14.59	203852	271121	67269
2011	5063.4	7.02	10.76	13.4	130450	249008	118557
Annual Average		**9.61**	**13.01**	**15.64**	**178487**	**290540**	**112054**

Notes: Volume of carbon stored as shown in equation (8). Prices are from BlueNext in current euros per ton of carbon dioxide equivalent (€/tCO_2e) traded in the global Certified Emission Reductions (CER) market. Based on atomic weights, for every 1 tonne of carbon sequestered, 3.67 tonnes of CO_2 are pulled from the atmosphere. **Source**: Author's calculations

Given the significant price volatility of the carbon market, a range of sequestration values were calculated using the minimum (Pmin) and maximum (Pmax) prices observed for each year. The change in total revenue between Pmin and Pmax (grey area in Figure 18) is also reported. The results indicate that average annual revenue from carbon sequestration in the Laguna de Rocha between 2008 and 2011 was between €178 487 and 290 540 current euros per year[17]. In order to trade, a stream of these revenues could be discounted over the time horizon specified for a given transaction.

As mentioned above, the objective of this exercise was to demonstrate the methodology and provide a first indication of the potential value of the carbon sequestration service in the Laguna de Rocha. That being said, there are several obstacles to entering the carbon market whose analysis was beyond the scope of this study but that would determine whether or not a value similar to the potential revenues reported in Table 12 can be realized. The first action required is an in-depth analysis of the regulations under the CDM and post-2012 climate regime to determine how carbon sequestration services from protecting coastal wetlands can be certified (or not). Assuming a positive

[17] Carbon prices are commonly quoted in euros because the vast majority of trading takes place in the EU

conclusion from the CDM analysis (which is a big assumption), the next step would be to determine if it's worthwhile to: i) determine the specific carbon accumulation rates of Uruguay's saline wetlands; and ii) go through the CDM certification process in order to trade in the global carbon market. The significant annual revenues reported in Table 12 indicate that it may be in Uruguay's interest (or any other countries' interest) to investigate this option further as a means of financing the management of coastal wetland protected areas.

6.3 Damage Costs Avoided Method: Impact of Climate Change on 'Habitat Maintenance' and 'Cultural' Ecosystem Services

The rationale for the following cost-based analysis arises from two observations of the reality in the Laguna de Rocha Protected Area. First, there is very little physical or 'hard' infrastructure in the protected area that can be damaged by climate impacts. Small, but important, exceptions are the fishing communities and other residences located on the lagoon sandbar and at the mouth of the Rocha River. The second observation is that there have been significant investments in 'soft' projects focused on conserving the relatively pristine state of the area through knowledge generation, capacity development, and policy planning. These projects have been implemented over the years by a number of actors including national and local government, academics, local producers and/or NGO's[18]. Building on these observations, I argue that conventional economic analyses 'miss' this significant mobilization of funds and that a cost-based methodology based on 'soft' project budgets can offer a rough indication of the economic value of the 'habitat maintenance' and 'cultural' ecosystem services (in the absence of market or surrogate market indicators).

For the purpose of valuing climate change impacts, a distinction can be made between projects that explicitly implement climate change adaptation/mitigation activities and other projects that do not explicitly address climate change. The damage costs avoided method simply takes the difference between the total costs of all projects from the costs of projects that do not explicitly address climate change to infer a monetary value of climate change impacts on habitat and cultural ecosystem services. Importantly, this method is often considered a last resort by economists because it is not measuring economic willingness to pay. Instead, the assumption is that, if people incur costs to

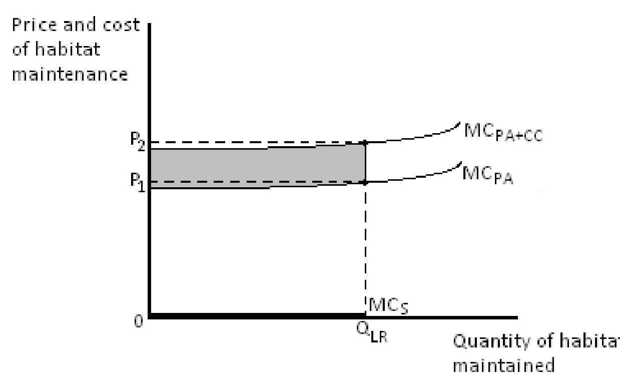
[18] In fact, the area has been the centre of so many projects in the region, often funded in part by international development organizations, that a feeling of 'project fatigue' was expressed by several individuals throughout the course of this study.

avoid damages from lost ecosystem services, then the value of those services must be *at least* what those people pay to avoid losing them (King and Mazzotta, 2000). This assumption is questionable but it was felt that there was benefit in opening a space for discussion by conducting the exercise of gathering the available historical data and demonstrating the methodology.

6.3.1 The Model: Damage Costs Avoided by Investing in Climate Change Adaptation and Conservation

The habitat maintenance service of the Laguna de Rocha refers to the ecosystem function of providing habitat to maintain the life cycles of migratory species (especially birds) and to maintain genetic diversity (de Groot et al., 2010). On the other hand, the cultural services here refer to the educational, aesthetic and spiritual/inspirational services that the protected area provides. I argue that the value inferred from using the proposed project-based damage costs avoided method should be considered a rough aggregate of all of these ecosystem services, since most projects have multiple objectives whose disaggregation was not possible due to data constraints (e.g. conserve migratory bird habitat AND develop capacity for sustainable cattle-raising methods).

Figure 19 – Climate change damage costs avoided through habitat conservation



Source: Loosely adapted from Barbier (2007)

Figure 19 illustrates the effects of climate change on the costs of avoiding damages from lost habitat maintenance. Without people around, the cost of the habitat maintenance services provided by the lagoon ecosystem are 'free' as shown by the MC_S line along the horizontal axis to the quantity of habitat maintenance service provided by the Laguna de Rocha, Q_{LR}. However, in a world of scarcity, people incur costs to protect habitat maintenance services (and the cultural services upon which they depend), MC_{PA}, from being damaged or destroyed by other land-use alternatives. The assumption is that the value of the ecosystem service must be worth at least the amount that people pay to protect it, or the area under the MC_{PA} curve between 0 and Q_{LR}. Avoiding damages from climate change increase the costs of protecting the area, MC_{PA+CC}, thus resulting in an increase in the value of the habitat maintenance service.

The inferred economic value of climate change impacts, V_{CC}, on the habitat maintenance services of the 22,000 ha Laguna de Rocha Protected Area is therefore at least the grey area between MC_{PA+CC} and MC_{PA}, or

$$V_{CC} = \Delta MC = \int_0^{Q_{LR}} MC_{PA+CC}dq - \int_0^{Q_{LR}} MC_{PA}dq \quad (12)$$

6.3.2 Results

Budgetary data dating back as far as 1986 were obtained for 46 projects (either in execution or completed) in the Laguna de Rocha Protected Area from various institutions[19]. Note that this list should not be considered exhaustive due to time limitations for data collection. One project was found that explicitly addresses climate change impacts in the Laguna de Rocha entitled 'Implementing pilot climate change adaptation measures in coastal areas of Uruguay'. It is a four year project currently in execution with a total budget of nearly 4 million dollars funded by the Global Environment Facility (GEF) with co-financing from the United Nations Development Programme (UNDP), the Uruguayan Ministry of Housing, Territorial Regulation and Environment (MVOTMA) and the Spanish Ministry of Environment (GEF, 2008). The project has chosen the Laguna de Rocha Protected Area as one of two pilot studies to implement climate change adaptation measures to implement 'specific pilot demonstration adaptation measures for ecosystems at risk under predicted climate change […] at local levels' (ibid). The project document allocates US$ 601,100 to this specific outcome for both sites and it is assumed that both sites receive equal amounts of funding, or ~ US$ 300,000 each. The remaining 45 projects were not found to explicitly address climate change impacts. Table 13 reports the summary statistics and results of the damage costs avoided valuation of habitat maintenance and cultural services.

[19] Institutions consulted include the *Dirección Nacional de Medio Ambiente (*DINAMA, National Environment Authority), *Universidad de la República* (UdelaR, University of the Republic), Global Environment Facility (GEF) and Aves Uruguay.

Table 13 – Summary statistics and results of damage cost method for valuing habitat maintenance and cultural services

Summary statistics of project budget data				
No. of projects	**Period**	**Mean ($\bar{x}$)**	**Std. Dev. (σ)**	
46	1986-2013	49,326	112,690	
Results of damage cost method				
	All Projects	**All projects less CC**	**Cost of CC**	**% increase from CC**
Total budget	2,269,000	1,969,000	300,000	**+13.2%**
Average annual budget	84,037	72,926	11,111	

Notes: Results based on total budgets of 46 conservation and research projects implemented/in execution in the Laguna de Rocha Protected Area between 1986 and 2013. Amounts are in current US dollars. CC: climate change. **Source:** Author's calculations

The results of the damage costs avoided method implemented using total project budgets in the area from 1986 to 2013 suggest that an inferred value of climate change impacts on habitat maintenance and cultural services in the protected area is US$ 300,000 over the 27-year period, or US$ 11,111/year on average. This method infers that changes in climate have increased the economic value of the habitat maintenance and cultural ecosystem services provided by the LRPA by at least 13.2%. The cost-based methodology demonstrated here makes the fundamental assumption that the costs incurred to avoid damages from climate change impacts to these services provide a useful estimate of the services' economic value. In the absence of a counterfactual, this method also assumes that the 46 projects implemented were demanded based on social preferences and that they contributed to avoiding damages from lost ecosystem services. There are questionable assumptions behind the inference of economic values from cost-based methodologies. However, their ease of implementation in a data and resource-constrained context makes them attractive for demonstrating the policy relevance, particularly *cost-effectiveness*, of maintaining ecosystem services in a changing climate (Heal et al., 2005).

6.4 Lessons learned from the empirical case studies

This chapter tested the feasibility and relevance of three monetary valuation methodologies for estimating the economic value of distinct ecosystem services using case studies from the Laguna de Rocha Protected Area. As with most empirical exercises, data availability, time and resources were constraining factors that largely determined the selection of methodologies that could be feasibly implemented in this study. That being said, a number of interesting valuation results on the non-market impacts of climate change were obtained with relatively minimal data requirements (and under specific assumptions). This section discusses the methodological lessons learned from the three case studies in the context of estimating monetary values for non-market impacts of climate change in developing countries.

Production Function Approach to Valuing Precipitation-Shrimp Linkages

The production function approach to valuing non-market inputs to production was shown to be a flexible method capable of estimating welfare impacts of precipitation changes on the LRPA shrimp fishery with minimal data requirements using standard economic techniques. A major advantage of this method is that the quantitative analysis provides a range of uncertainty around the monetary point estimate. In our case, the model estimated that the 195.5 mm increase in average annual rainfall observed in Rocha between 1961 and 1998 caused a total welfare loss to the LRPA shrimp fishery of US$ 1,335 (US$ 258 to 234,732 at 95% confidence), or US$ 6.83/mm (US$ 1.32 to 1,200.68 at 95% confidence).

Issues with this method are mostly related to biased results stemming from model mis-specification including: i) unknown ecological and economic interactions; and ii) incorrect choice of functional form and elasticities of substitution. Barbier (2007) argues that a dynamic approach that models intertemporal changes in shrimp stocks produces estimates with a smaller range of uncertainty than the results from the static approach implemented in this study. As always, the reliability of estimates from quantitative models is based on the accuracy of the physical data with which they are “fed”. Welfare estimates from the precipitation-shrimp model demonstrated also rely on the assumptions of neoclassical economics (e.g. perfect competition, profit-maximizing behaviour, etc.) that may be unrealistic in the LRPA fishery. All in all, this study agrees with the literature that recommends the production function approach as an inexpensive and fairly rapid means to provide reasonably accurate estimates of economic values (including uncertainty ranges) for changes in ecosystem services as long as the ecological-economic relationship is fairly well-known (Pearce and Moran, 1994; Barbier, 2007).

Market Price Approach to Valuing Carbon Sequestration Services

Using the market price method is particularly relevant for the case of carbon sequestration services, given that the existence of the carbon market can be considered a direct 'impact' of climate change (Kulshreshtha, 2000). Carbon market data was obtained from 2008 to 2011 and a proxy soil carbon accumulation rate for the LRPA was calculated based on an average of twelve similar coastal wetland sites. The main lessons learned from the market price approach to valuing LRPA carbon sequestration were: i) changes in quantities of carbon traded in the market explain next to none of the considerable variability in carbon prices; and ii) the small quantity of carbon sequestered by the LRPA has virtually no impact on carbon demanded in the market. That being said, those conclusions should be considered preliminary given that a more experienced market data analyst could come up with very different results.

Based on the negligible impact on consumer surplus from the carbon market price analysis, the most relevant monetary estimate of the LRPA carbon sequestration service was considered to be a first estimate of the potential financial revenue from trading it in the CDM carbon market. The results indicate that potential annual revenue from carbon sequestered in the LRPA ranged from € 178,487 to 290,540 over the period of analysis. Beyond the use of a proxy carbon sequestration rate due to a lack of *in situ* observations, the main valuation issue with these financial results is that economic willingness-to-pay (e.g. preferences) is not captured (Rothman et al., 2003). Furthermore, this analysis does not include the costs or eligibility of 'bringing' LRPA carbon to market whereas, in reality, the regulations related to granting CERs under the CDM mechanism are substantial. As such, the result of the financial analysis conducted arguably provides an upper-bound approximation relevant to Uruguayan authorities for deciding whether or not more research into this option is worthwhile.

Damage Costs Avoided Method to Value Climate Impacts on Habitat Maintenance and Cultural Services

Cost-based methodologies are most relevant as a last resort for valuing ecosystem services lacking market or surrogate market data (Barbier, 2007). With this in mind and lacking other options, I argued that an aggregated value of habitat maintenance and cultural ecosystem services identified for the LRPA could be inferred from expenditures on conservation/research projects using the damage costs avoided method.

Furthermore, the value of climate impacts on the above services was inferred from the additional cost of projects that explicitly address climate change. Budgetary data totalling more than US$2 million was obtained from 46 projects implemented in the protected area over the last 25 years and one project was identified that explicitly addresses climate change. The results from this method indicate that climate change has increased the economic value of the habitat maintenance and cultural ecosystem services by at least US$300,000, or roughly 13%.

In practice, there are at least two questionable assumptions behind these results. First, the financial costs incurred to avoid damages from climate change are assumed to provide a meaningful estimate of societal value for the benefits provided by the ecosystem services being protected. Second, the logic of ‘bundling’ habitat maintenance and cultural ecosystem services together as performed in the analysis is questionable since it was a qualitative decision made based on the reality of data/resources available. Other analysts could attribute project costs to other ecosystem services. An argument for performing this type of analysis is that the costs of implementing ‘soft’ conservation projects in the LRPA provides a rough indicator of an appreciation (value) of the area that could not feasibly be captured by any other methodologies.

CHAPTER 7: CONCLUSION

This study provided an assessment of the relevance and feasibility of monetary valuation methodologies for estimating historical climate impacts on the Laguna de Rocha ecosystem. Some general points for discussion and opportunities for future research that arose during the course of this study are outlined below.

The climate in Rocha is changing.

In order to answer whether or not the climate in Rocha is changing, Chapter 2 explored how climate systems can change and identified specific trends in the local climate based on an analysis of data collected over the past fifty years that corroborates with the peer-reviewed literature. Table 3 summarizes the observed climatic trends in Rocha and shows significant long-run increasing trends for temperature (+0.2°C/10 yr), precipitation (6.7mm/yr) and sea-level rise (2.9 mm/yr). Two issues are important to highlight from this approach. First, the trend analysis focused on long-run linear averages so climate variability at other time scales (interdecadal, annual, interannual) was not incorporated into the assessment. The second issue is related and has to do with uncertainty about future trends, especially precipitation. Essentially, there is debate about whether precipitation in Uruguay will continue to increase as the long-run trends show or whether the past 30-40 year increase in rainfall is the result of a decadal oscillation that may be coming to an end (Hirata et al., 2010). Issues surrounding future climate variability/climate change and risk management are the topic of much debate and research all around the world, including Uruguay (Baethgen, 2011). While these issues are incredibly important, I do not address them in this study because my feeling is that the *process* of implementing monetary valuation methodologies ought not to be overly affected by the choice of time horizon. Clearly, there is scope here for much more research.

The LRPA provides numerous ecosystem services that are vulnerable to climate change.

After identifying the long-run climate trends in Rocha to be used in the study, the task for Chapter 3 was to answer what ecosystem services are physically provided by the LRPA and how, if at all, are they vulnerable to a changing climate? Based on a physical and ecological characterization of the protected area, Table 6 identifies 11 ecosystem services, the geographical area within the LRPA that each is located and a description of how they are vulnerable to observed climate changes. In order to permit a certain level of international comparison, the LRPA ecosystem service identification utilized the state-of-the-art in international ecosystem assessment frameworks developed for *The Economics of Ecosystems and Biodiversity (TEEB)* project. The 11 ecosystem services identified for the LRPA were categorized into provisioning (2), regulating (4), habitat (1) and cultural (4) services. The main issue with any attempt to classify the many benefits provided by ecosystems is that nature is not easily compartmentalized and one ‘item’ can have multiple values (e.g. a fish provided by the Laguna de Rocha has a market value and also a cultural value to the individual that identifies him/herself as an LRPA fisher). While the classification proposed for the LRPA is certainly open to debate, the literature suggests that there will probably never be a *final* classification scheme for the benefits provided to humans by ecosystems (de Groot et al., 2010). Rather, the articulation of the multiple benefits provided by a particular ecosystem is context-specific based on the issue at hand and the need to be able to measure how specific ecosystem services can be degraded (or not) by ‘external’ factors like a changing climate.

The monetary valuation of ecosystem services can provide a relevant indicator to inform natural resource management decisions as long as their limitations are recognized.

To move beyond what ecosystem services are biophysically provided by the LRPA, Chapter 4 shifted into the socio-economic sphere by asking how conventional economics measures what the identified services are actually “worth” to people. In particular, the philosophical basis of neo-classical economic value as the contribution to the social goal of individual utility maximization was elaborated upon and contrasted to other social goals such as ecological sustainability and a just distribution of resources. I argued that, when done well, the results of cost/benefit analysis (CBA) and monetary valuations in a two tiered reflective/action decision-making process (Figure 15) can be found in the ‘action’ tier as one indicator representative of allocative efficiency goals. Conventional economic analysis does not have anything to say regarding ecological sustainability or equity goals so other indicators are required for informed decision-making. Furthermore, the outcomes of decisions informed by, inter alia, CBA criteria could be evaluated to reflect upon the relative weights given to the multiple criteria for future decision-making in the ‘reflective’ tier.

Climate change impacts on ecosystem services can be analyzed with the Total Economic Value (TEV) framework.

The ecosystem services identified using the TEEB ecosystem assessment framework for the LRPA could be adapted to the total economic value (TEV) framework of direct use, indirect use, insurance/option and non-use values that environmental economists are more familiar with. The conceptual mapping of LRPA ecosystem services in the TEV framework (Figure 16) showed that different monetary valuation methodologies are more or less relevant depending on the economic use value of the ecosystem service being measured. Impacts of climate change on direct uses of ecosystem services such as fishing, hunting or recreation are the easiest to place an economic value upon since people can often be observed consuming the service in question. There are fewer options for valuing indirect uses of ecosystems such as storm protection because they are not 'traded' directly so economic value has to be either inferred from the costs of substitutes or measured through changes in economic productivity attributed to changes in the ecosystem. Finally, methodologies under the stated preference approach are the only methods capable of measuring non-use monetary values of ecosystems such as the value that can be attributed to simply knowing that a species or ecosystem exists.

The 'change in productivities' method is the most relevant and feasible methodology for estimating the economic value of climate 'inputs' to the main productive activities in the LRPA.

Chapter 5 examined a sample of approaches – revealed preference, stated preference, cost-based and benefit transfer – to estimating monetary values for the ecosystem services identified in the LRPA. Of the revealed preference approach methods, Table 8 shows the 'change in productivities' method as the most relevant and feasible for estimating the value of climate impacts on the ecosystem services upon which LRPA fishing and farming activities depend (e.g. direct provisioning and/or regulating services). The disadvantages of this method are largely related first to data availability and then to difficulties modelling the relationship between environmental changes – climate, in our case – and the productive activity. In particular, the presence of ecosystem tipping points and other non-linear responses to climate changes imply that simple linear relationships may be inadequate (Pearce and Moran, 1994). The limiting factor in the LRPA for applying this method was the requirement for local historical production data for each sector that was either non-existent or difficult to collect given time and resource constraints.

I demonstrated the method in Chapter 6 with a case study of precipitation changes on the LR shrimp fishery using a (dated) nine-year dataset reported in Santana and Fabiano (1999). Table 10 shows that the total welfare loss to the flow of shrimp capture in the Laguna de Rocha due to the linear increase in rainfall observed between 1961 and 1998 were US $1,335 ($258 to 234,732 with 95% confidence) or US $6.83/mm ($1.32 to 1,200.68 with 95% confidence). In this particular case study, the model suggests that increases in average rainfall have had a significant negative impact on the welfare of shrimp fishers in the Laguna de Rocha (Figure 17). A major advantage to this method is that the statistical range of uncertainty around the monetary welfare impact of increased precipitation was also estimated. That being said, the confidence bounds surrounding the point estimate are quite large suggesting caution interpreting these results for policy analysis as technical issues surrounding model specification (e.g. choice of functional form, elasticity of substitution, etc.) can lead to biased results. However, the point estimate is on the low end of the estimated range suggesting that the model generates a conservative estimate. Future research could likely improve the results by incorporating a 'dynamic' approach that models the impact of precipitation on shrimp stocks over time. All in all, this study agrees with the literature that recommends the production function approach as an inexpensive and fairly rapid means to provide reasonably accurate estimates of economic values (including uncertainty ranges) for changes in ecosystem services as long as the ecological-economic relationship is fairly well-known (Pearce and Moran, 1994; Barbier, 2007).

The market price method can be particularly relevant for valuing the carbon sequestration services of the LRPA.

Kulshreshtha et al. (2000) argue that the sequestration of carbon from the atmosphere by wetlands has only attained an economic value as the damages from anthropogenic climate change have become more evident. As such, the very existence of the carbon market can be considered a direct 'impact' of climate change and the conventional market price method can be relevant and feasible to implement as long as the physical quantity of carbon sequestered by the ecosystem is known and market data is available. I undertook a case study for the LRPA and found that next to none of the variability in carbon prices was explained by changes in carbon quantities traded based on linear and iso-elastic demand equations estimated from almost four years of daily CDM trading data. Furthermore, even if the demand equations had been significant, I concluded that the small quantity of carbon sequestered by the LRPA relative to the global market would not have a measurable impact on consumer surplus (Figure 18). As such, I argued that exogenous 'price shocks' are the norm in the CDM carbon market so the most relevant monetary estimate for the LRPA would be a financial assessment of potential revenue based on maximum and minimum prices observed.

The financial assessment summarized in Table 12 found that average annual revenue from carbon sequestration in the LRPA between 2008 and 2011 was between €178,487 and 290,540 current euros per year. However, this analysis does not include the costs or eligibility of 'bringing' LRPA carbon to market whereas, in reality, the regulations related to granting CERs under the CDM mechanism are substantial. As such, the result of the financial analysis conducted arguably provides an upper-bound approximation relevant to Uruguayan authorities for deciding whether or not more research into this option is worthwhile. This preliminary analysis could certainly be improved through further research looking at other carbon markets and/or by implementing a comparative 'substitute cost' analysis of the value of the next-best alternative land use.

'Hedonic Pricing', 'Travel Cost' and 'Contingent Valuation' methods were relevant for some ecosystem services but were not feasibly implemented in this study.

Table 8 shows that the hedonic pricing, travel cost and contingent valuation methods were judged to have low to medium feasibility in the LRPA depending on the ecosystem service/valuation methodology pairing. Hedonic pricing is highly relevant for valuing changes in the aesthetic ecosystem service but was found to have low feasibility for application in the LRPA due to heavy data requirements. The travel cost method is highly relevant for valuing changes in recreational use due to climate change impacts however the timing of this study did not coincide with the summer tourist season when the LRPA receives the majority of its visitors. Contingent valuation is a highly relevant and flexible way to estimate internally consistent measures of economic value for ecosystem services not related to any markets. However, the application of the results of contingent valuations to real-life situations is controversial due to observed response biases to hypothetical valuation questions. Guidelines in survey design/implementation exist to help avoid these biases however they come at a high cost in terms of time and resources that were not available for this study.

Cost-based methods can provide a rough indicator of economic value but are not as relevant as other monetary valuation methodologies because they do not measure preferences.

The broadly related cost-based methods assume that useful values can be inferred from the additional costs incurred from either avoiding damages due to lost ecosystem functions, replacing environmental assets or providing substitute services (King and Mazzotta, 2000). This assumption may or may not be true since it is well-accepted that costs are often not an accurate measure of benefits (Barbier, 1997). However, it can be much easier to measure costs so Table 8 shows that these methods are the most feasibly implemented for a number of ecosystem services in the data-scarce LRPA and arguably give a rough indicator of economic value.

A case study of the damage costs avoided method was shown in Chapter 6 through an analysis of the proportion of climate change-related investments in conservation projects in the LRPA. The results from this method shown in Table 13 indicate that climate change has increased the economic value of the habitat maintenance and cultural ecosystem services by at least US$300,000, or roughly 13%. In other words, the case study suggests that ecosystem services provided by the LRPA become more valuable in a changing climate.

In practice, there are at least two questionable assumptions behind these results. First, the financial costs incurred to avoid damages from climate change are assumed to provide a meaningful estimate of societal value for the benefits provided by the ecosystem services being protected. Second, the logic of ‘bundling’ habitat maintenance and cultural ecosystem services together as performed in the analysis is questionable since it was a qualitative decision made based on the reality of data/resources available. Other analysts could attribute project costs to other ecosystem services. An argument for performing this type of analysis is that the costs of implementing ‘soft’ conservation projects in the LRPA provides a rough indicator of an appreciation (value) of the area that could not feasibly be captured by any other methodologies.

Climate change is impacting the economic value of ecosystem services in the LRPA.

The most general lesson learned from this study is that monetary valuation methodologies were found to be useful tools for linking the global issue of climate change with local impacts on ecosystem services as long as their limitations are kept in mind. However, decision-making should be informed by multiple criteria as complex ecological-economic interactions and modelling of climate change scenarios far into the future push these methodologies to their limits (and beyond, in some cases) (Rothman, et al., 2003). The discussion and case studies show that various methodologies can be feasibly implemented to put a monetary value on climate impacts observed on the ecosystem services within a protected area. Some methodologies are clearly more relevant from an economic theory perspective and accordingly produce more acceptable results. In particular, the production function method is shown to be highly relevant in isolating economically and statistically significant climate impacts on production and fairly feasible to implement, even in data-scarce developing countries. Social preferences for ecosystem services can be difficult to quantify so, while cost-based estimations provide an option for inferring a rough indicator of value, they should always be accompanied by additional evidence that a given ecosystem service is actually demanded. That being said, when it comes to choosing the most *cost-effective* option to adapt to future climate change impacts, the cost-based methods can be powerful tools for weighing alternative adaptation options (Rothman et al., 2003).

This study sought to provide a discussion on how the economic value of historical climate changes on ecosystem services can be measured based on data from a coastal lagoon in Uruguay. I argued that a focus on valuing past and current climate impacts is useful as a precursor to examining the relevance of valuation methodologies under even more uncertain future climate change scenarios. While there is certainly scope for more research, one could expect that the relevance and feasibility of implementing the methodologies analyzed here to value *past* climate impacts need not be the same as when looking at *future* impacts. Moving forward, the information collected and analyzed in this study has arguably provided a baseline upon which to build further study on the economic impacts of climate change in the Laguna de Rocha in the future. By responding to calls for more accurate monetary estimates of climate change impacts in developing countries, including non-market values, it is hoped that the approach taken here to assess monetary valuation methodologies will be useful for future analysts and stakeholders involved in measuring, and making decisions regarding, climate impacts on ecosystems.

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APPENDIX 1: ADVANTAGES AND DISADVANTAGES OF MONETARY VALUATION METHODOLOGIES

Table A.1: Advantages and disadvantages of revealed preference, stated preference and cost-based monetary valuation methodologies

Methodology	Advantages	Disadvantages
MARKET PRICE	Standard technique on observed behaviour	Market data may not reflect multiple uses of a resource
	Data exists	Prices may not reflect economic value due to market/policy failures
	Values are well-defined for market goods	Overstates benefits if costs of other inputs are not deducted
CHANGES IN PRODUCTIVITY	Standard technique for valuing costs of factors of production	Limited to valuing resources used as factors of production
	Market data exists	Difficult to apply when changes to the natural resource affect the market price
	Straightforward when substitutes for the natural resource exist (e.g. irrigation vs. rain-fed agriculture)	Understates benefits if the ecosystem provides services not related to the production of marketed goods
HEDONIC PRICING	Estimates WTP for environmental quality/amenities based on physical housing and neighbourhood characteristics	Limited to environmental benefits related to housing prices
		Requires large amounts of data collection and manipulation
	Straightforward when data exists	Only captures WTP from *perceived* differences in environmental attributes
TRAVEL COST	Similar to standard economic techniques for estimating WTP based on actual behaviour	Does not provide information on anticipated changes in conditions from CC
	On-site surveys provide opportunity for large data samples	Non-use values of recreational sites are not captured
	Results are relatively easy to interpret and explain	Methodological issues related to opportunity cost of time, multi - purpose trips and substitute sites

CONTINGENT VALUATION	Can be used to estimate total economic value of an ecosystem (use and non-use values) Relatively easy to analyze and describe results (assuming the survey is well-designed) Substantial literature and guidelines on survey design	Not based on observed or actual behaviour Estimates of non-use values are difficult to validate externally Disparity observed between WTP and WTA Considerable risk of biased results Many people do not believe the results of CV
DAMAGE COSTS AVOIDED	Relevant for estimating adaptation costs of climate change Generally easier to estimate than WTP for ecosystem services	Not based on economic theory of value Costs are not usually an accurate measure of benefits Assumes the magnitude of damage costs are measurable
REPLACEMENT COSTS	Data and resource needs are relatively small and methods are straightforward to implement	Preferences for ecosystem services not considered Environmental values limited to ecosystem services
SUBSTITUTE COSTS	Provides a rough indicator for economic value when WTP cannot be estimated	Assumes built environment is an acceptable alternative to lost ecosystem services
BENEFIT TRANSFER	Relatively cheap Useful when data required to conduct original study does not exist Can be used as a screening method	At best, results are only as accurate as the initial values Economic values may not be accurate at all for many site-specific and/or methodological reasons Good studies may not be available or study quality may be difficult to assess

*Acronyms: CC – Climate change WTP – willing-to-pay; WTA – willing-to-accept; CC – Climate change; CV – contingent valuation; GIS – Geographic Information Systems;