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Vulnerability to climate change in Uruguay: potential impacts on the agricultural and coastal resource sectors and response capabilities

Annie Hareau[1,*], Raúl Hofstadter[2], Andrés Saizar[3]

[1]Paraguay 1321, Esc. 802, Montevideo 11100, Uruguay
[2]Sistemas Hidráulicos Ltda., Paysandú 1439, Montevideo 11100, Uruguay
[3]Dirección Nacional de Medio Ambiente, Rincón 422, Montevideo 11000, Uruguay

ABSTRACT: Uruguay's economy is mostly based on the use of natural resources that are affected by the strongly variable climate conditions to which the country is exposed. Climate changes induced by greenhouse warming are likely to enhance the country's vulnerability to environmental phenomena and are thus a matter of concern. The analyses carried out, particularly regarding crops, grasslands, and coastal resources, have evidenced the need to develop advanced response strategies framed within sectoral development plans. The type and sign of the effect on crop production would vary, depending on the crop involved. Grassland production is likely to be favored by increased temperature conditions, while precipitation deficiencies or increased variability would be detrimental. The predicted changes in sea level, even the most conservative, would put at risk high capital value land and infrastructure along the Uruguayan coast. Since the coast is frequently affected by storms, the overall vulnerability would also be determined by changes in storm patterns. It was observed that while appropriate conditions are encountered at both the technical and political levels to address changes that may affect the agricultural sector, a considerable effort is required to develop integrated coastal zone management plans that combine general and private interests and include responses to climate change.

KEY WORDS: Climate change · Vulnerability · Response capabilities · Agriculture · Coastal resources · Uruguay

1. INTRODUCTION

Uruguay (approximately 180 000 km^2 and 3 150 000 inhabitants) is located in temperate South America. Its climate, fairly homogeneous throughout the country, is defined as mesothermic subhumid according to the Köppen classification (Köppen 1931). The land is characterized by a low, rolling topography. Water resources (both surface and groundwater) are abundant. Grasslands, considerably modified by grazing and agricultural practices, are the dominant vegetation, while native forests ranging from dry moist to humid (according to the Köppen life zone classification) are found along rivers and streams and on the slopes of hills. Wetlands cover a considerable portion of the southeastern region and are present in small areas at other sites. Deep to shallow brown and black soils with good fertility cover a considerable part of the country. The typical management practice in agricultural soils consists of rotation of crops and pastures for cattle production.

The Uruguayan coast stretches along 680 km on the Río de la Plata and the Atlantic Ocean. Six out of the 19 departments into which the country is divided are located on the coast (Colonia, San José, Montevideo, Canelones, Maldonado, and Rocha, from W to E). The coast is characterized by sandy beaches bounded by rocky headlands and migrating sand dunes. A series of coastal lagoons are present along the oceanic coast. The coastline is recurrently affected by storms and has been considerably modified as a result of urban and touristic development.

*E-mail: barte@adinet.com.uy

Agricultural production accounts for approximately 11 % of the gross domestic product (GDP), which totals about US$ 20 billion, and also provides most of the raw material for the local industries (which account for another 20 % of the GDP). The agricultural sector is oriented to beef and wool production on natural grasslands (covering 85 % of the country), dairy production, and crop production (in about 4 % of the territory). Crops include subtropical and temperate species, mainly wheat and barley as winter crops, and maize, rice, sorghum and sunflower as summer crops. Beef, wool, hides, and cereals account for about one-third of total exports.

Tourism, mainly to coastal areas, is another major economic activity in the country. Its direct contribution to the GDP is about 4 %. Tourism has resulted in the development of resort areas with significant foreign investment, construction of roads and infrastructure, and enhanced development of the service sectors. Summer is the high season.

The Río de la Plata is a vast fluvio-marine system, highly variable in both space and time. Since Uruguay is located downstream of its large basin, which also comprises part of Brazil, Paraguay, Bolivia, and Argentina, it is subject to the impacts of development projects and activities carried out in these countries, as well as to the climatic phenomena occurring in the region. Such impacts are most remarkable with regard to the availability, use, and management of water resources. The Río de la Plata flows into the Southwestern Atlantic Ocean, close to the confluence of the Malvinas and Brazil currents. The complex ocean-land-atmosphere interactions associated with these systems are a determining factor of the strong natural variability in the region.

This study addresses the general vulnerability to climate change of 2 sectors of particular importance to the country's economy: the agricultural sector (both crop production and grasslands for cattle production) and the coastal resource sector. The study also includes an overview of the current and potential capabilities for responding to the expected impacts. Interest in the agricultural sector lies in the fact that it has traditionally been the basis of both the country's economy and the people's way of life. The relevance of the coastal sector is mainly due to 2 facts: (1) that almost 70 % of the country's population lives along its coasts and is linked to a greater or lesser extent to its resources, and (2) the importance of the tourist industry in the coastal zone. As described below, the vulnerability of the coastal sector is addressed in this study particularly in relation to impacts on currently or potentially urbanized areas — in terms of land, construction, and infrastructure loss — while other possible impacts are assessed only qualitatively.

2. METHODOLOGY

2.1. Assessment of agricultural sector vulnerability. The assessment was based on results from analyses performed for the Uruguay Climate Change Country Study (UCCCS), which are briefly described below, and on available background information. The vulnerability of the sector was evaluated taking into account the socioeconomic conditions with which the potential physical changes would interact.

During the UCCCS, 5 general circulation models (GCMs) were tested for the southeastern South American region by Hofstadter & Bidegain (1997): the Goddard Institute for Space Science (GISS) model, the Geophysical Fluid Dynamics Laboratory (GFDL) R-30 model, the GFDL 1 % model, the United Kingdom Meteorological Office UK89 model, and the Canadian Climate Centre Model (CCCM). All 5 provided good temperature simulations but unsatisfactory estimates of the regional precipitation patterns. Therefore, agricultural model runs were made mainly under incremental climate conditions (changes of +2 and +4°C in temperature and ±10 and ±20 % in precipitation, applied to the baseline climate values covering periods of 20 to 30 yr).

2.1.1. Crop production subsector analyses: The simulation model results used for this assessment were those obtained from the application of the Decision Support System for Agrotechnology Transfer (DSSAT) v3.1 CERES models for barley, wheat, and maize crops (Baethgen 1994, Baethgen & Magrin 1995, Romero 1996, Sawchik 1996, CNCG 1997). The calibration of the crop models for the UCCCS was performed based on field experiments with the cultivars most used in the country (2 to 3 cultivars per crop) and at different planting dates. Even though such calibration is considered preliminary due to its short duration, it served the purpose of a general vulnerability evaluation of the crops. Validation was performed by comparing model outputs with historical data gathered for a long-existing national cultivar evaluation program. Since calibration and validation of the CERES-rice model during the UCCCS produced unsatisfactory results (CNCG 1997), outputs from this model were not taken into account for the discussion in this study.

2.1.2. Grassland/livestock subsector analyses: The SPUR2 model, mainly its plant and hydrology submodels, was used for the grassland/livestock analyses during the UCCCS (Chiara & Cruz 1997, CNCG 1997). The model was run for 3 different types of soils, representative of the most important livestock production regions of the country: a deep fertile soil (typic peludert), a shallow fertile soil (lithic udorthent), and a deep, low-fertility sandy soil (mollic hapludalf). An interactive calibration was carried out with the input of appropriate parameter sets for each submodel. Validation was performed by comparing model outputs with historical data.

2.2. Assessment of coastal zone vulnerability. *2.2.1. Sea level rise scenarios:* During the UCCCS, the local sea level rise over the century was estimated (Forbes & Chao 1996) to determine the most likely scenarios for the coastal analysis. The values obtained (0.07 mm yr^{-1} at Punta del Este Port and 0.7 mm yr^{-1} at Montevideo Port) were compared to the global mean value (1.8 mm yr^{-1}) estimated by Douglas (1991) and to the records from other tide gauge stations in the Southwestern Atlantic Ocean (about 1.5 mm yr^{-1}). Since the relatively lower historical rise observed along the Uruguayan coast could not be explained, the local conditions under a global climate change scenario are highly uncertain. Therefore, it was necessary to assume that the study area would be exposed to a sea level rise within the ranges estimated by the IPCC. The scenarios selected for the year 2100 include rather conservative values: 0.30, 0.50 and 1.00 m.

2.2.2. Impact assessment: The area under study, which covers most of the Uruguayan coast (560 km between Colonia del Sacramento and the Arroyo Chuy), was divided into 14 zones of fairly homogeneous characteristics. The impact of sea level rise was measured in terms of land loss due to erosion under the selected scenarios by means of 2 models for estimating shoreline recession: (1) the Bruun Rule (Bruun 1962) and (2) a dynamic equilibrium model, which was developed by Texeira & Lorenzo (1996) for the UCCCS, as described in CNCG (1997), and which is referred to as 'Equilibrium' in Tables l & 2.

Given that the Bruun Rule is considered to underestimate shoreline recession while the Texeira & Lorenzo (1996) model results in higher estimates, the application of both together provides 2 possible extreme values for shoreline recession.

A quantitative analysis of potential land loss and the associated capital at risk was performed. This analysis particularly referred to actual and potential urban development, due to the high capital values involved. A mean value per unit area was calculated on the basis of the present values of land, construction, and infrastructure for each coastal zone. This value was used to estimate the capital at risk in the areas at risk of erosion. Full occupation of the areas that are currently only partially occupied and no change in the non-urbanized areas was assumed. Values were projected to the year 2100 using a 4% annual rate of increase for infrastructure and a doubling of the current price for real estate. These values were compared with the estimated costs of protection measures, which were calculated, in the case of seawalls, based on the unit concrete price and a basic seawall design, and, in the case of beach nourishment, on the international price for sand (CNCG 1997, Saizar 1997).

The evaluation of other potential impacts of climate changes along the coast was performed qualitatively for this study on the basis of current observations and background information.

2.3. Assessment of socioeconomic conditions. Evaluation of the current and potential socioeconomic conditions relative to both agricultural and coastal resources sectors, which will ultimately determine the magnitude of the impacts and the response capabilities, was based mainly on the observation of general trends during the past few decades. Such trends were analyzed within the framework of the current situation in the country and in the region. This does not mean that actual projections were made, but rather that the most likely future situations were outlined.

3. RESULTS AND DISCUSSION

3.1. Agricultural sector

As described below, it was observed that the effects of potential climate changes on the Uruguayan agricultural sector would vary in type and sign (that is, whether the effect is positive or negative) for different production systems. A series of feasible measures, both anticipatory and reactive, were preliminarily identified to respond to these changes.

3.1.1. Crop production subsector

3.1.1.1. Vulnerability of crops to climate change: Climate change would affect the normal environmental conditions required by the crops, consequently affecting their cycles. Barley, which is very sensitive to its environment, would be particularly vulnerable to changes in climatic parameters. Romero (1996), based on CERES-barley outputs and analysis of historical series, observed that a considerable decrease in yield could occur as a result of an increase in winter temperatures. The impact would be due, on the one hand, to the crop's requirements for cold temperatures not being fulfilled and, on the other, to a reduction in the duration of the growth cycle. The latter could result from the lack of response to the photoperiod by the barley cultivars, which react to accumulated thermal time rather than to the duration of daylight. Further, as a result of an earlier anthesis date induced by higher temperatures, the incident solar radiation during the grain-filling period would be lower, and yield would be consequently reduced.

Precipitation changes would also considerably affect barley yields since one of the main limiting factors for winter crop production is excessive soil water (which causes poor root aeration and nitrogen stress). An increase in rainfall could then result in lower yields and vice versa.

Wheat crops could be affected under changed temperature and precipitation conditions in a manner similar to that of barley. However, given that the wheat cultivars normally used in Uruguay are characterized by their response to the photoperiod, the impact on this crop of an increase in temperature might be less significant than in the case of barley. The vulnerability of winter crops to climate change in Uruguay has also been discussed by Baethgen (1994) and Baethgen & Magrin (1995).

Maize, mostly produced in Uruguay under rainfed conditions, is usually affected by soil water deficiencies during summer. The environmental conditions for maize crops would be worsened if the future climate entailed a decrease in precipitation. On the other hand, the potential increase in temperature could result in lower yields due to a reduction in the duration of the crop cycle. Climate change might favor maize production only if the amount of rainfall during summer increased, provided that nitrogen deficiencies are controlled. The behavior of maize crops under climate change scenarios has been further analyzed by Sawchik (1996) based on CERES-maize model outputs.

According to past observations, rice crops in Uruguay could be favored by an increase in temperature that improved the environmental conditions required for anthesis and grain filling. This could not be proved, however, by means of the CERES-rice model, given that, in the case of this crop, the outputs from the preliminary model runs were inconsistent with actual data (CNCG 1997). On the other hand, since the crop is grown under irrigated conditions, potential changes in precipitation might affect the volumes of available water and thus the extent of the cultivated area (either an increase or a decrease, depending on the scenario involved).

3.1.1.2. Response options and capabilities: A most likely response with regard to crop production is the progressive adaptation of the cultivars to the new environmental conditions. This might occur both as a natural and as a human-induced process, through either selection of varieties suited to new conditions or genetic improvement. The winter crop cultivars adapted to an increased mean temperature could be characterized by lower cold-temperature requirements and a stronger response to the photoperiod. To reduce the potentially negative effects of an increase in temperature during certain development and growth stages, varieties with modified cycles as compared with the currently used cultivars would be required in the case of both winter crops and maize. In the case of rice, adaptation should be directed toward taking advantage of the potentially positive effect of an increase in temperature.

In response to an excess of soil water under an increased precipitation scenario, new cultivars with higher resistance to soil anaerobiosis would be appropriate. Resistance to diseases and pests, likely to become an increasing problem under scenarios with higher temperature and precipitation conditions relative to the baseline climate, should also be considered. The capability at the national level for testing new cultivars and conducting genetic improvement is reasonably high. High levels of research experience as well as the technical and logistical capacity for this purpose exist at institutions such as the Instituto Nacional de Investigación Agropecuaria (INIA).

Changes in management practices are also feasible as reactive measures to respond to climate change. This could include, for example, changes in planting dates to compensate for the crop cycle modifications induced by new temperature conditions, fertilization to compensate for N loss under excess soil water conditions, and irrigation under decreased precipitation.

Although the chances of timely adaptation to temperature changes are fairly good (which does not mean that there will be no negative impacts or costs involved), the response to precipitation changes is of greater concern. First, the uncertainties as to the sign and magnitude of the changes prevent appropriate planning. Second, the possibility of precipitation variability being augmented implies that current unfavorable conditions resulting from climate variability might be worsened. Third, adaptation to either positive or negative changes in precipitation (such as fertilization and irrigation, respectively) would be costly. A thorough cost-benefit analysis would therefore be required.

Independent of their cost, responses to precipitation changes are considered to be technically possible. Adoption of policy measures would be required (for example, credits or tax exemptions) to facilitate their implementation. Government-producer cooperative programs with support from international organizations, such as those that assist in the development of irrigation capacities in the country, are appropriate mechanisms for facilitating the adaptation process.

In addition, technological development applied to agricultural production, which is increasingly being paid attention to by national farmers, would improve crop yields and establish more favorable conditions for responding to environmental changes.

3.1.2. Grassland/livestock subsector

3.1.2.1. Vulnerability of grasslands to climate change: According to the results of the SPUR2 model runs described in Chiara & Cruz (1997) and CNCG (1997), the most favorable scenario for grasslands would include increases in both temperature and precipitation. Forage production under such conditions could increase by about 60 % on shallow soils of the Uruguay Basalt region. These soils are of medium to high fertility and well drained, characterized by winter pasture growth, and subject to severe water deficiencies in summer. The area is mostly used for raising sheep and calves. The forage increase could be about 50 % on the deep, low-fertility, and well-drained soils on the Tacuarembó Sandstones, characterized by high pasture production during summer (appropriate for calf raising), which significantly decreases in winter. Although less significant, an increase (30 %) could be expected as well on deep and fertile soils of the Basalt region. This area is characterized by a better forage distribution throughout the year due to a higher water availability in summer, and it is mainly used for calf breeding and cattle fattening.

Even though grassland/livestock production would be, in general terms, favored under the scenario above, recurrent periods of excessive rainfall resulting in flooding of large extensions of low grazing lands could have a relatively negative effect.

Under scenarios with lower precipitation than the baseline situation, the positive effect of temperature on forage production would be less significant and the interannual variability would increase. The results obtained for this situation could be indicating a positive effect on the plant physiology of higher atmospheric CO_2 levels, which could partly compensate for the detrimental effects of a decrease in rainfall. However, if it is assumed that short-term climate variability is equal or higher under the climate change scenario as compared to the present situation, the positive effect of global warming on winter forage might not be significant enough to counteract the negative impacts of such variability. This applies in particular to precipitation variations, which are the major determining factor for annual production in the country.

3.1.2.2. Response options and capabilities: Response of the grassland/livestock sector to climate change should concentrate on taking the best possible advantage of the favorable effect that a temperature increase might have on forage production, while minimizing the risks associated with a potential decrease in precipitation or an increase in its variability. Such a response would include primarily adaptation of management practices and policies (such as grain and forage storage, water reservoirs for cattle, and financial and technical assistance).

Organizations that involve both the government and the private sector have been established at the national level to respond to critical situations resulting from the short-term climatic variations. These include, for example, inter-institutional commissions to address the effects of droughts and other emergencies. However, considerable effort is still required to achieve stable and consistent policies and devise strategies to reduce the sector's vulnerability.

3.2. Coastal resource sector

3.2.1. Socioeconomic conditions

The Uruguayan coastal area is considerably developed. Urban centers (including ports and industries located within the cities) occupy approximately 35 % of the coast, while agriculture (crops and rangelands) and forestry occupy 18 %. The remainder consists of non-urban areas and, to a minor extent, sand mining plots (particularly in the Colonia department, followed by Montevideo and San José). A large number of activities carried out within the coastal zone are directly or indirectly related to tourism and recreation.

Most uses of the coast have resulted in degradation processes. Besides, there exists a tight relationship between coastal occupation and its vulnerability to climatic phenomena—from the physical standpoint because it modifies the erosion processes, and from the socioeconomic standpoint because it increases the capital at risk. Erosion in urban areas has led to the construction of protective structures, which periodically require maintenance (such as seawalls along the coast of Montevideo city).

The definition of future socioeconomic scenarios relative to the coastal zone is particularly difficult due to the almost sustained increase in urban development and in the use of coastal resources without an integrated development plan. It is possible, however, to envision general situations in accordance with the main trends in the area and in view of existing development projects.

The most dramatic changes along the Uruguayan coast likely would result from the construction of the international Colonia-Buenos Aires Bridge, should it be finally approved. This 42 km-long bridge is projected to be completed during the first decade of the 21st century. It would link the city of Colonia in Uruguay, of about 20 000 people, to the Buenos Aires metropolitan area in Argentina, of about 13 million people. Even though the project has included environmental impact considerations, the sensitivity of the coast would inevitably increase both as a direct effect of the bridge itself and indirectly as a result of increased occupation and use of the coast. Special attention should therefore be paid in this area to the potential impacts of climate changes, both as part of the bridge design and construction and of other development plans in the area.

Montevideo, where the capital city covers most of the coast, is the smallest but most densely populated department. It is possible that future socioeconomic conditions, including international investments, would cause the city to grow westward of the Montevideo Bay (where the old city and the port are located). However, development of the Montevideo urban area has historically occurred eastward. Thus the 'Ciudad de la Costa' (Coastal City) has been rapidly developing along the coast of Canelones department, mainly during the past decade, as a suburb of Montevideo city. This is the area with the highest population growth rate in the country. Although the population density in the Ciudad de la Costa is much lower than in Montevideo, it is foreseen that urbanization in this area and other coastal sites of Canelones will continue to increase. Consequently, stress on coastal resources and their sensitivity to climate changes would be enhanced.

Maldonado, including the international resort area linked to Punta del Este, has been subject to large investments in coastal infrastructure that have strongly modified the coast. It is expected, however, that some sectors of this department will be preserved as rural areas. In the case of Rocha, the easternmost department on the oceanic coast, coastal development has been considerably slower. The potential construction of bridges over the lagoons, which would improve road communications along the coast, is likely to increase its use. Both the design of such infrastructure and the development in the already plotted coastal area should take into account the potential effects of climate change.

3.2.2. Vulnerability to sea level rise

The analysis on which this study is based was performed only with regard to land loss due to erosion induced by sea level rise. It should, however, be taken into account that the actual effect of a climate change would ultimately depend on the combination of various factors in addition to the level of the sea, such as the prevailing wave conditions and the flow regime of the rivers and streams that discharge into the Río de la Plata or along the oceanic coast. It is worth mentioning that, under present conditions, some sectors of the coast are exposed to rises in sea level even higher than 1 m, resulting from high precipitation conditions in the Paraná and Uruguay river basins or from storm surges caused by S or SE wind storms.

Although it is considered that the estimates described here, performed during the UCCCS, carry several uncertainties, they allow for a comparative evaluation in economic terms of the possible damage and response measures in the different areas.

Under the assumption that the areas currently urbanized become fully occupied by the year 2100, it was observed that the capital at risk per unit of coast is considerably higher in some sectors than in others. This is particularly the case for the Maldonado-Punta del Este resort area (Zone IX in Table 1, from Punta Ballena to José Ignacio), followed by Montevideo city and the adjacent Ciudad de la Costa in Canelones, included in Zone VI. Table 1 displays the projected capital value at risk relative to each coastal area, considering the estimated land loss based on use of both the Brunn Rule and the dynamic equilibrium model.

In addition to the effects mentioned above, sea level rise might cause other effects in the Uruguay coastal areas; these were analyzed only qualitatively. Such impacts include, in the first place, the potential inundation and salinization of lowlands and of the lower course of the water flows that discharge along the coast. The Santa Lucía river deserves special attention, considering that it is the source of drinking water for Montevideo and its surrounding urban areas.

Inundation along the margins of the lower course of coastal streams might affect some urbanized areas, particularly in Montevideo and Canelones, and eventually agricultural lands. Erosion and inundation are currently serious problems at some sites (such as at the mouth of the Arroyo Pando in Canelones), which would be aggravated under sea level rise conditions.

The coastal lagoons should also be regarded as especially sensitive to a potential increase in sea level, possibly combined with changes in the precipitation regime and in the effects of waves and storm surges, which would affect the dynamics of the lagoon sand pits. This would result in changes in the system that might affect its biota, which is of high ecological and commercial interest. The area inundated by the lagoon would also increase, possibly affecting the wetlands. Rice production in the lower lands of this area might be affected as well by salinization.

Some other possible effects have been identified, although a more specific evaluation is required for each case. They include, for instance, the indirect impact on tourism, ports, and industrial activities, mainly as a result of changes in coastal morphology and damage to infrastructure.

3.2.3. Response options and capabilities

Possible responses to climate change were analyzed particularly with regard to the potential risk to urban

Table 1. Projected capital value at risk (in 10^3 US$) per unit of coast (in km) in each zone for land loss estimated using the Bruun Rule and the dynamic equilibrium model

Zone	Limits	Sea level rise 0.30 m Bruun	0.30 m Equilibrium	0.50 m Bruun	0.50 m Equilibrium	1.00 m Bruun	1.00 m Equilibrium
I	Colonia – Pta. Artilleros	290	1 251	1 297	2 514	3 128	5 084
II	Pta. Artilleros – Arroyo Pereira	276	634	609	1 352	1 583	3 134
III	Arroyo Pereira – Playa Pascual	103	335	539	817	1 624	1 634
IV	Playa Pascual – Pta. Espinillo	329	687	546	1 431	1 370	2 861
V	Pta. Espinillo – Pta. Lobos	2	5	1	8	7	16
VI	Pta. Lobos – Atlántida	13 903	38 527	23 178	113 854	81 939	342 305
VII	Atlántida – Pta. Colorada	1 820	4 898	3 034	10 404	7 732	25 512
VIII	Pta. Colorada – Pta. Ballena	14 929	42 536	24 881	106 339	74 643	273 909
IX	Pta. Ballena – Pta. José Ignacio	44 965	132 321	74 942	330 801	224 825	992 404
X	Pta. José Ignacio – La Paloma	5 974	15 365	9 956	38 413	29 869	115 240
XI	La Paloma – Pta. Castillos Grande	275	819	459	2 029	1 364	6 052
XII	Pta. Castillos Grande – Pta. del Diablo	9	27	15	46	29	91
XIII	Pta. del Diablo – Pta. Loberos	9	27	14	45	28	89
XIV	Pta. Loberos – Barra del Arroyo Chuy	76	238	126	396	253	793

areas under the urban development assumption above and considering solely the effects of a rise in sea level.

It would seem reasonable to implement, as much as possible, anticipatory response measures that have benefits and no costs, or an initial cost significantly lower than any possible reactive response. With this in mind, it is first observed that accomodation measures (as defined by IPCC 1992), which in the case of Uruguayan construction would imply a full reconstruction, would not be feasible. The same would apply to moving coastal structures landward.

The adoption of hard protection measures (seawall construction), although costly, would be justified in certain areas with either important infrastructure (such as coastal roads and buildings) or high values (such as the Colonia del Sacramento historical area and main residential areas). The same applies for soft measures (beach nourishment), which could be required for the most used beaches (for example, in Montevideo and in the main seaside resort areas) in case they became too eroded. Coastal protection, which is considered to be of high cost in Uruguay (as earlier observed by Volonté & Nicholls 1994, 1995, and also discussed by Nicholls & Leatherman 1995), would then be justified in areas where the capital at risk exceeds the adaptation costs. The comparison between the projected value of the capital at risk and the protection costs (hard and soft protection measures) in all 14 coastal areas analyzed for the UCCCS, for both the Bruun Rule and the equilibrium model land loss estimates under each sea level rise scenario, is shown in Table 2. As indicated previously, it should be kept in mind that the equilibrium model provides a higher estimate of erosion than the Bruun Rule. The areas where the value of the capital at risk exceeds the cost of protection options are shown in italics. Note that the highest figures correspond to Zone IX (the Maldonado-Punta del Este resort area), followed by Zone VI (Montevideo, together with the Ciudad de la Costa and other coastal urban areas of Canelones). Zones VII, VIII, and X include cities or resorts in Canelones, Maldonado, and Rocha. Although the positive figures shown for Zone I, which includes Colonia, are rather low and only apply to hard protection for the equilibrium model land loss estimates, it is foreseen that socioeconomic development in the area as a result of construction of the Colonia-Buenos Aires bridge would cause a rapid increase in the capital at risk.

In addition to the possible adoption of protection measures, which would be technically feasible in most cases, the implementation of planned retreat measures could be appropriate. This could include restrictions for building in vulnerable areas, promoting and planning urban development in non-sensitive areas, expropriating lands in critical zones, or preventing reconstruction of damaged properties. Except for expropriation, these options would have no direct costs for the government. However, they would almost inevitably generate conflicts, because it hardly would be possible to benefit all those involved (for example, coastal land owners, real estate agents, tourist agents, and the government).

The feasibility of adopting the planned retreat measures must be considered in light of the legislation in force at the national and municipal levels. Especially important for this purpose is, on the one hand, the 'Ley de Centros Poblados' (Urban Centers Development Law), passed in 1946. By this law it was established that all land plots for urbanization should stand at least 150 m away from the coastline. On the other hand,

Table 2. Comparison of the projected capital value at risk (CAR) and the protection costs (in 10^3 US$) by means of seawalls (SW) and artificial beach nourishment (AN)

Zone	Limits	0.30 m sea level rise				0.50 m sea level rise				1.00 m sea level rise			
		Bruun		Equilibrium		Bruun		Equilibrium		Bruun		Equilibrium	
		CAR – SW	CAR – AN	CAR – SW	CAR – AN	CAR – SW	CAR – AN	CAR – SW	CAR – AN	CAR – SW	CAR – AN	CAR – SW	CAR – AN
I	Colonia – Pta. Artilleros	–17 368	–64 777	10 376	–37 033	–14 031	–84 467	21 115	–49 320	–12 633	–153 505	43 854	–97 017
II	Pta. Artilleros – Arroyo Pereira	–35 884	–122 508	–14 936	–101 560	–68 490	–195 515	–25 040	–152 065	–115 594	–369 644	–24 867	–278 917
III	Arroyo Pereira – Playa Pascual	–48 730	–120 915	–34 412	–106 597	–76 890	–178 819	–59 668	–161 596	–119 939	–323 796	–119 335	–323 192
IV	Playa Pascual – Pta. Espinillo	–5 034	–17 279	–332	–12 577	–11 534	–28 825	71	–17 219	–19 432	–54 013	142	–34 438
V	Pta. Espinillo – Pta. Lobos	–2 876	–7 737	–2 822	–7 682	–5 828	–12 955	–5 676	–12 803	–11 535	–25 789	–11 352	–25 606
VI	Pta. Lobos – Atlántida	680 114	627 269	1 949 638	1 896 794	1 121 656	1 045 794	5 796 451	5 720 589	4 077 841	3 926 117	17 500 979	17 349 255
VII	Atlántida – Pta. Colorada	59 621	–8 761	240 607	172 225	83 566	–14 602	516 911	418 743	265 015	68 681	1 310 482	1 114 148
VIII	Pta. Colorada – Pta. Ballena	347 236	319 024	1 025 543	997 331	572 207	531 706	2 573 638	2 533 137	1 755 738	1 674 737	6 651 696	6 570 695
IX	Pta. Ballena – Pta. José Ignacio	2 173 329	2 114 233	6 475 153	6 416 056	3 608 558	3 523 721	16 208 367	16 123 530	10 907 617	10 737 943	48 707 043	48 537 369
X	Pta. José Ignacio – La Paloma	258 395	167 329	737 640	646 575	415 174	278 882	1 867 326	1 731 034	1 338 424	1 065 840	5 694 877	5 422 293
XI	La Paloma – Pta. Castillos Grande	–34 380	–118 065	–2 987	–86 672	–74 059	–196 774	16 635	–106 081	–122 318	–367 749	148 386	–97 046
XII	Pta. Castillos Grande – Pta. del Diablo	–42 021	–112 645	–41 144	–111 768	–84 179	–187 741	–82 718	–186 280	–168 357	–375 482	–165 435	–372 560
XIII	Pta. del Diablo – Pta. Loberos	–11 294	–30 279	–11 055	–30 040	–22 626	–50 465	–22 228	–50 067	–45 252	–100 931	–44 455	–100 134
XIV	Pta. Loberos – Barra del Arroyo Chuy	–22 757	–64 091	–18 315	–59 649	–46 207	–106 818	–38 803	–99 415	–92 414	–213 637	–77 606	–198 829
	Total	3 298 351	2 560 798	10 312 954	9 575 403	5 397 317	4 323 122	26 766 381	25 692 187	17 637 161	15 488 772	79 614 409	77 466 021

regulations relative to coastal construction are included in the 'Código de Aguas' (Water Act), passed in 1978, under which a permit is required for any projected construction within 250 m of the shoreline (taken as the high tide mark) at all sites that are not behind a coastal road. Such a permit is granted by the Dirección Nacional de Medio Ambiente (DINAMA) when it is considered that the potential modification of the coastal morphology resulting from the effects of the construction would be tolerable. Furthermore, by the 'Ley de Impacto Ambiental' (Environmental Impact Assessment Law), passed in 1994 and also enforced by the DINAMA, it was established that all development projects should be accompanied by an environmental impact assessment.

In spite of the importance of the above legislation and other relevant regulations, the establishment of conservation and development principles for the coastal zone, agreed upon by the government and societal actors and included in integrated management plans, is still lacking. This complex task, requiring interinstitutional cooperation (both national and international), is considered an essential step for enabling the adoption of effective response measures to climate change that combine general and private interests.

4. CONCLUSIONS

Uruguay is considered to be sensitive to long-term climate changes as a result of their potential effects on sectors of particular socioeconomic importance, such as agriculture and coastal development. Although there is a general consensus at the international level on the future conditions related to global warming, the uncertainties with respect to the sign and magnitude of precipitation changes and climate variability patterns result in uncertainties as to future conditions for such sectors in Uruguay.

The effects of climate change on crop production would differ depending on the crop involved. While an increase in temperature might be detrimental particularly for winter crops (that is, barley and wheat), it could have a positive effect on some summer crops such as rice. With regard to precipitation, its increase could be detrimental to winter crops but favorable for rainfed summer crops such as maize. The effects of a decrease in precipitation would be, roughly, opposite.

Climate change would also have an influence on the grassland/livestock sector, although in this case the effect is expected to be mostly positive as a result of higher forage production. Special attention should be paid, however, to the possibility of an increase in climate variability (particularly in precipitation), which is currently the main determining factor for grassland production.

Should appropriate response measures be adopted in a timely manner, the overall sustainability of the agricultural sector would probably not be at a significant risk. The adoption of technical measures (such as genetic improvement and changes in management practices) would be feasible given the long-term experience of agricultural research applied to production in Uruguay. Implementation of policy measures and response strategies consistent with the new environmental and production conditions would be required.

Independent of the national situation, it should also be taken into account that the agricultural sector would continue to be affected by international trade conditions. A potential increase in world food demand affecting Uruguayan exports (whether related or not to climate change) would result in the increased overall sensitivity of the sector.

Uruguayan coastal resources are also vulnerable to global climate change. Under sea level rise scenarios, the capital at risk due to land losses would be high in urbanized areas, particularly in the Maldonado-Punta del Este resort area and in Montevideo. Other sites of high economic, ecological, or recreational interest (such as beaches, coastal lagoons, wetlands, and agricultural areas) might also be affected. Although the costs of hard or soft protection would be high, such investment would be justified in the areas most vulnerable in terms of sensitivity to erosion and relative value (economic, historical, recreational, and so forth).

Development will likely continue along most of the coast. The most dramatic changes would occur as a result of the construction of the Colonia-Buenos Aires bridge. Such a scenario, combined with the threats to the coast of the current and potential wind and wave climate changes, places a high priority on the development of integrated coastal zone management plans. Plans should include, on the one hand, scientifically based criteria and limitations for the design and construction of coastal structures in order to minimize coastal degradation under the predicted environmental changes and, on the other hand, programs for arresting development in the most sensitive zones.

In summary, there exists in Uruguay appropriate technical capacities to respond to climate change in order to reduce the impacts on major economic activity sectors. However, a considerable effort is still required to develop the relevant intra- and inter-sectoral plans and policies with the consensus of the government and the private sectors.

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