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Use of Natural and Artificial Accretion on the North Coast of Spain: Historical Trends and Assessment of Some Environmental and Economic Consequences

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ABSTRACT

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The evolution of estuarine and coastal wetland zones along the sector between the Deva and Bidasoa rivers, after the Flandrian maximun, is analyzed using air photographs, old maps and charts, and field observations. The aims of this study were to quantify historical development of the land reclamation process in the area and to assess some of its environmental and economic consequences.

The total area emerged during the post-Flandrian retreat was approximately 24 km^2. The new land areas formed afterwards cover some 73 km^2. Out of these, around 64 km^2 are estimated to be due to direct human intervention (draining, filling and reclamation). This artificial area represents 40% of the estuarine and wetland zones.

Assuming an uniform rate of accretion (an obvious simplification) it appears that new land spaces were formed, through natural processes, at a rate of about 0.22 km^2/century after the Flandrian retreat. The approximate distribution of land-use types in the artificially created lands is: 36% agriculture, 22% industry, 14% residential, 13% others and 15% without use.

A comparative assessment of the biological productivity, in terms of the monetary value of products obtained by the primary sector shows that the substitution of intertidal or wetland areas by agricultural lands represents, at present, a loss of about $US 250,000 km^{-2} year^{-1}. This substitution affects 58% of the reclaimed lands. An estimate of the "willingness to pay" by the population, in order to preserve the aesthetic qualities and recreational potential of these areas indicates that the population of the region value this resource around $US 200 × 10^6 per year.

The filled areas are, on the whole, less than 1 m above sea level. Therefore, a sea level rise of about 1 m, as predicted by several models for the next centuries, would endanger 73 km^2 of post-Flandrian natural and artificial lands. The capital value of buildings, structures, *etc.* on this land has been estimated around $US 5,000 × 10^6.

ADDITIONAL INDEX WORDS: *Land reclamation, sea-level rise hazards, biological productivity, primary productivity, coastal evolution, and environmental assessment.*

INTRODUCTION

The population pressures exerted on the coastal fringe resources of the Cantabrian littoral during the last two centuries have resulted, among other things, in a marked concentration of population (80%) in a narrow strip 10–15 km wide. In the two coastal states studied, Cantabria and Euskadi, or Basque Country ("Comunidades Autónomas" according the Spanish administrative organization), the population amounts to 2,400,000 inhabitants, of which over 1,500,000 live in the three main urban-industrial centers, Santander, Bilbao and San Sebastián-Pasajes (Figure 1). The growth of these and other, smaller coastal centers has taken place, to a certain extent, through the occupation of intertidal areas and coastal wetlands, especially around estuaries. The trends observed in the rate of reclamation some ten years ago (200,000 to 300,000 m^2 year^{-1} in Santander; CENDRERO and DIAZ DE TERAN, 1977; CENDRERO *et al.*, 1981) indicated that, if maintained, the intertidal zones and marshes could disappear towards the middle of the next century. More recent observations (RIVAS and CENDRERO, 1987; CENDRERO *et al.*, 1988) have shown that those trends changed little in the last decade.

The concern for the future of such fragile coastal areas has prompted legal actions to preserve some of them. Thus, the "Ria de Guernica" (Figure 1) has been declared a Biosphere

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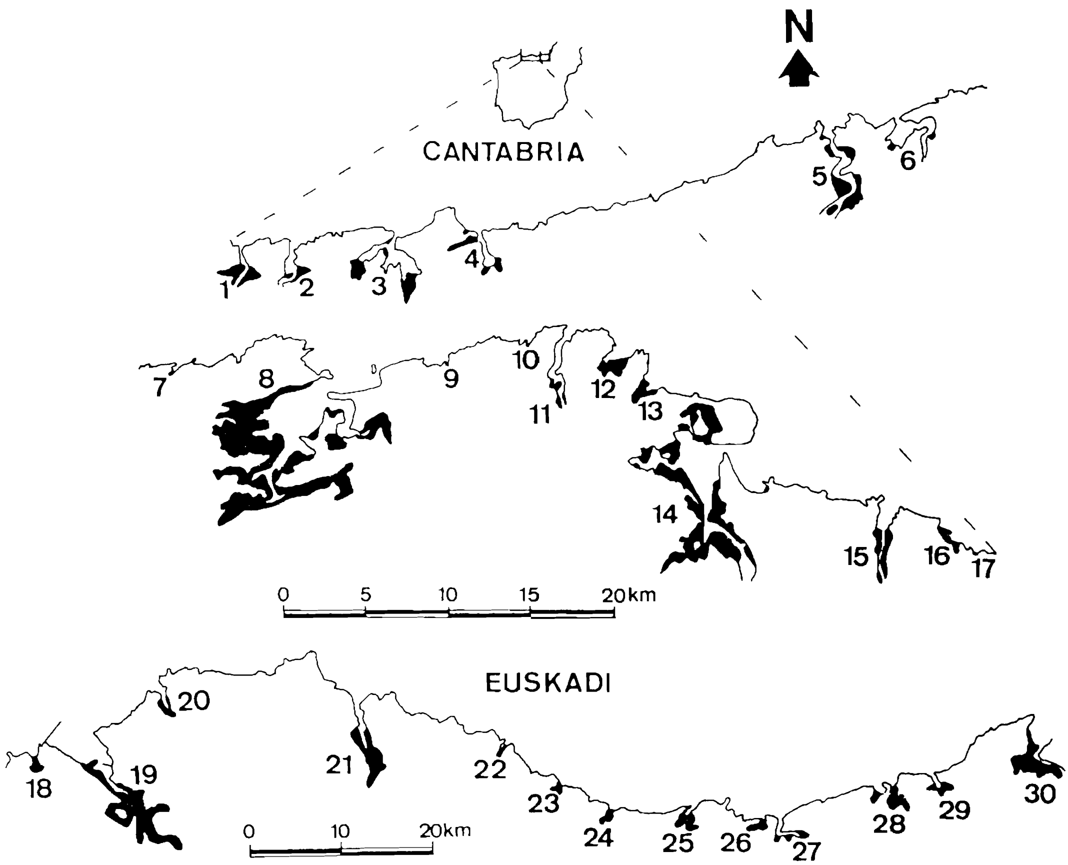

Figure 1. Reclaimed intertidal and wetland zones in the eastern Cantabrian coast. (1) Tina Mayor, (2) Tina Menor, (3) San Vicente de la Barquera, (4) La Rabia, (5) San Martin de la Arena, (6) Pas, (7) San Juan de la Canal, (8) Bay of Santander, (9) Galizano, (10) Cuberris, (11) Ajo, (12) Soano, (13) Trengandín, (14) Asón, (15) Oriñón, (16) Castro Urdiales, (17) Mioño, (18) Somorrostro, (19) Bilbao, (20) Plencia, (21) Guernica, (22) Lequeitio, (23) Ondárroa, (24) Deva, (25) Zumaya, (26) Zarauz, (27) Orio, (28) San Sebastián, (29) Pasajes, (30) Fuenterrabía.

Reserve by UNESCO, and is now protected by a recent law of the Basque Government (ARRIOLA *et al.*, 1988). The Ria del Asón (Figure 1) has been declared a Coastal Wetland of International Importance by the Council of Europe.

However, no precise data have been available about the extent of the process and rate of occupation of such zones by man. There are no estimates of possible environmental or economic consequences of the process, nor of the consequences that an eventual rise of sea-level might have for the region (TITUS, 1986; BRUUN, 1988; FAIRBRIDGE, 1989; SCHNACK and PIRAZZOLI, 1990).

The aims of the work presented in this paper are: (1) to quantify the historical development and present extent of the process of reclamation of intertidal and wetland zones, (2) to establish the rates of surface accretion and to compare them with the rates due to natural sedimentation during the Holocene, (3) to define the relationships, if any, between changes in the type of socio-economic activity and coastal land reclamation in the region; also, to establish the present land-use of reclaimed lands, and (4) to attempt a preliminary estimate of some economic consequences of the occupation of intertidal areas, both regarding the change in productivity and the potential effects of sea level rise.

METHODS

The approach followed has been very simple. The "zero line" established as a reference against which the coastal changes were compared was the one corresponding to the Flandrian maximum in the zone. The Flandrian terraces, located 1–2.5 m above the present sea level and often with beach or estuarine sediments, have been dated as 5,880 ± 130 to 4,770 ± 110 years BP (MARY, 1979; MOÑINO, 1986). They normally present a slope break in the upper limit and a scarp at the lower one, although sometimes the transition is gradual and without distinct limits. Usually, the soils formed over the sandy or silty sediments have a fairly well developed A horizon. The terraces were mapped in order to establish the maximum extent of the estuaries and coastal wetlands at the Flandrian maximum. Their lower limit was used as the starting point of the "historical" evolution.

By means of old maps and navigation charts (normally not earlier than the beginning of the last century) as well as air photographs of various dates and scales (between 1957 and 1988; 1:30,000–1:7,500), the successive changes of the coastline were mapped. The operating procedure included the initial identification of some clear features of the coastline on the oldest maps and the transfer of such features to modern photographs and maps (scale 1:10,000). The areas mapped were then checked and completed by direct field observations. Thus, for each coastal area studied, a map was made in which the areas covered in successive periods were represented. These areas were measured with a planimeter and graphs showing the rate of surface reclamation in each estuary were obtained.

The evolution of the reclamation process was compared with the demographic evolution of the region. This was done using census data from 1860 onwards. For earlier dates data are scarce, but this is not too relevant in this context, because very little reclamation took place before that date. A comparison was also made with the changes experienced in the main productive activities in the area through the consultation of historical sources (MADOZ, 1850; ESCAGEDO, 1919; ASUA, 1930; ORTEGA Y GASSET, 1946; BARREDA, 1948, 1951; SOTA, 1950; ARIJA RIVARES, 1951, 1953, 1955; MAZARRASA, 1953; MAZA, 1965; BLAZQUEZ, 1970; GUAL CAMARENA, 1970; ALCALA ZAMORA, 1974; CASADO, 1980; MERCAPIDE, 1980; GOMEZ PORTILLA, 1982, 1984; ARIJA DUFOL, 1984; ORTEGA, 1984, 1986; AZURMENDI, 1985; SANCHEZ GOMEZ, 1987; HOYO, 1988) which indicate clearly the periods of flourishment of different activities (colonial commerce, mining, dairy farming, industry, tourism). Air photo interpretation and field observations also were used to map, at the 1:10,000 scale, the different land-use types established over the reclaimed areas.

Estimates of some environmental-economic consequences of the reclamation process were made, regarding the following aspects: (a) change in biological productivity, on the basis of the value of products obtained by the primary sector, (b) loss in potential for recreation and in aesthetic quality, (c) capital value of the buildings and structures subject to sea-level rise hazard.

Biological productivity in the intertidal areas was assessed on the basis of measurements made in the estuary of the river Pas (PEREZ, 1987) and by comparison with data obtained elsewhere (POMEROY, 1959; GUNNERSON, 1963; CENDRERO *et al.*, 1981). The average of the values obtained is 109 gC m^{-2} $year^{-1}$, equivalent to 1,363 grams of primary producers per square meter every year.

Several possible food chains were then considered to obtain the potential amount of fish of commercial value which could be produced (MARGALEFF, 1974). Three examples of such chains are:

(1) Primary producers—sediment eaters (E = .01)—crustaceans(E = .10)—red mullets (E = .012)—humans (E = .001)

(2) Primary producers—copepods (E = .21)—sardines (E = .15)—humans (E = .001)

(3) Primary producers—mussels (E = .03)—humans (E = .001)

This natural biological productivity (potential fish catches) was compared with its equivalent in terms of products obtained by the primary sector on the reclaimed lands of the region; that is, dairy produce. To obtain this, data were gathered on the average number of cows per km^2 in the area, as well as on their average milk production.

Alternatively, the commercial value of the biological productivity of the intertidal areas was estimated on the basis of the actual production of claims in a zone under control by the Spanish Institute of Oceanography, in the Bay of Santander (CENDRERO *et al.*, 1981). The production in this zone is 34,000 kg km^{-2} $year^{-1}$, and its total average value, at $US 18 kg^{-1}, $US 612,000 km^{-2} $year^{-1}$.

But the environmental change represented by the reclamation of intertidal and wetland areas has also consequences on the capability of these coastal zones to support recreational activities and on their aesthetic quality. Both aspects are considered as valuable by the population living in the region as well as by the many tourists who visit it. The assessment of these aspects in monetary terms is more difficult, because it does not refer to products with a specific market value. However, estimates can be made using the methods described by CLAWSON and KNETSCH (1971), KRUTILLA and FISHER (1975) and LOPEZ DE SEBASTIAN (1975) to determine the "willingness to pay" by the potential users and beneficiaries of the quality of the estuaries. Such estimates were made by means of a public opinion survey carried out among the population in the area of the Bay of Santander (CENDRERO *et al.*, 1981). The results obtained in this area are considered, in principle, representative for the whole region, because the economic and social conditions are very homogeneous in the three provinces covered in this work.

Another important aspect to be taken into consideration (although quite different from the former ones) is the possible effect of an eventual rise in sea level on the reclaimed lands. To assess the consequences of sea level rise, the total area potentially affected was determined (by measuring the zones lower than 1 m above present sea level, corresponding essentially to historically reclaimed lands) and the capital value of buildings, structures, utilities, etc. was estimated.

In the case of urban areas, the number of dwellings was obtained by air-photo counting and from the census data. An average surface was calculated for each dwelling (80 m^2) and multiplied by the present, average, cost ($US 1,000 m^{-2}). The average value of $US 80,000 was multiplied by the average number of dwellings per square kilometer in each type of urban zone, resulting in a mean value of $US $240 \times 10^6 km^{-2}$.

In industrial areas, the average surface, per square kilometer, covered by installations (100,000 m^2) was obtained from air photos and maps. According to the Department of Urban Planning of the University of Cantabria, the average cost of construction for such installations is $US 600 m^{-2}. This gives an average value of $US $60 \times 10^6 km^{-2}$. Adding the cost of utilities, roads, etc., the total average value would be $US 70×10^6 km^{-2}.

The total number of kilometers of different types of roads and railroads was measured, and the construction costs, per kilometer, were obtained from the Department of Public Works. These costs vary between $US 90,000–780,000 km^{-1} for roads and $US 260,000–2,600,000 km^{-1} for railroads. In this zone the values used are $US 435,000 km^{-1} for main roads, $US 174,000 km^{-1} for other roads and $US 870,000 for railways. The average value for areas covered by large structures such as airport, port installations and railroad stations, according to estimates provided by the port, airport and railway authorities, would be about $US 100×10^6 km^{-1}.

In agricultural zones the average number of buildings (farm-houses, stables, *etc.*) per square kilometer was determined by sample counting on air photographs, and multiplied for the average cost of such buildings, obtaining a figure of $US 4×10^6 km^{-2}. Other permanent installations in these areas are negligible.

Finally, installations and services such as streets, public parks, etc. represent 10% of the value of urban zones ($US 24×10^6 km^{-2}). Commercial buildings and shops amount to another 10% (estimates from the Department of Urban Planning of the University of Cantabria). In the case of utilities, such as power and telephone lines, water, sewage, *etc.* the average cost, per user, was obtained from the different companies, and multiplied by the number of users in the zones potentially affected. This value, nevertheless, represents only a small fraction of the other factors considered, not greater than 5%, of the value of the dwellings.

HISTORY OF HUMAN OCCUPATION AND NATURAL PROCESSES

The results obtained on the evolution of human occupation of intertidal areas are summarized in Figures 1–6 and Tables 1–4. It can be seen that not a single estuarine or coastal wetland zone has been free from human occupation in recent historical times.

The total intertidal and marsh areas lost amount to nearly 73 km^2, (46.9 in Cantabria and 25.8 in the Basque Country), representing 45.3% of the area which existed after the post-Flandrian retreat (Table 1). The least affected of the estuaries is the one of the river Pas (.285 km^2, 12.6%) and the most affected one Somorrostro (2.13 km^2, 81.6%). Only the Bay of Santander, with some 22×10^6 km^2, accounts for about one third of the reclaimed area.

In the same period, natural sedimentation (itself including the consequences of human actions in the river basins) accounts for an accretion of no more than 9 km^2. The accumulated volume of fill, considering an average thickness of 2 m, is about 43×10^6 m^3 in Cantabria (and probably about 22×10^6 m^3 in the Basque Country).

Although the data available for the 19th Century are not very precise for some zones, the process of filling and reclamation in Cantabria seems to have been particularly intense in the period between 1875 and 1925, during which more than half of the surface was reclaimed. Nevertheless, the rate of filling in more recent periods has also been substantial.

The average rate of the artificial process, considering the period 1788–1988, was about 0.32 km^2 $year^{-1}$; or, for a total length of 216 km of coastline (in a straight line), 1,481 m^2 km^{-1} $year^{-1}$. In the case of Cantabria, where the data about the evolution are more satisfactory, the rates for the period 1860–1925 were 0.35 km^2 $year^{-1}$ and 1,620 m^2 km^{-1} $year^{-1}$, and for 1970–1988, 0.25 km^2 $year^{-1}$ and 1,157 m^2 km^{-1} $year^{-1}$.

Assuming an uniform rate of accretion (an obvious simplification) it appears that new land spaces were formed, through natural processes, at a rate of about 0.22 km^2/century after the Flandrian retreat. The average rate of artificial accretion since the process started (no more than 250 years ago) has been around 25 km^2/century, but in the last 130 years it has exceeded 35 km^2/century.

There are, of course, significant differences in the variation of filling rates with time, from one estuary to another. Thus, the Ria of Tina Mayor had lost 98.3% of its surface by 1925 and it has experienced practically no changes since, and the Ria of Somorrostro, which in 1970 had been very little affected, was nearly totally filled (over 80%) by the end of the same decade. Figures 2 and 3 show examples of the evolution of reclamation in two estuaries.

The present use of the new land obtained is shown in Table 3, and some examples in Figures 4 and 5. It can be seen that agriculture accounts for about 36% (26 km^2), urban plus industrial use for another 36% and the un-used areas for 15% (about 11 km^2). It is interesting to point out that the reclamation process has meant, to a great extent (more than half), the substitution of highly productive wetlands by agricultural lands of fairly poor productivity, because of the low quality of the soils. The biological productivity of these agricultural lands is 8–16 times lower than that of estuaries (RYTHER, 1969). This difference in biological productivity is also reflected in the economic productivity as discussed below.

In the case of Cantabria, a total of 5.6 km^2 (12.1% of the areas lost) are totally or partially isolated, un-used zones, which could be recovered very easily, simply by partial demolition of the enclosing walls. In the case of drained areas (without filling) devoted to agriculture, restoration of intertidal or marsh conditions would only be slightly more difficult. It has been observed in some zones, like the estuaries of San Vicente or of the river Asón, that the abandonment of cultivated areas and the breaking-up of the enclosing walls has led, in a very short period, to the reinstauration of the normal estuarine or wetland environments. In particular, in the Asón estuary, areas which appeared cultivated in the 1957 air photographs were already undistinguishable from other, surrounding marsh areas in 1970. The areas in this situation represent 15.6 km^2 (33.2%) of the reclaimed lands of Cantabria. In the Basque Country this would affect to 25–30% of the new lands. Therefore, the breaking-up of the walls enclosing isolated and drained areas, a very low cost operation because these walls are nearly always made of loose materials, would allow the recovery of nearly half the former estuarine and wetland zones reclaimed. The financial cost of the compensation to present owners or users and the comparison with the ecological benefits to be obtained should be evaluated. The data obtained here in relation to

Table 1. *Evolution of the Cantabrian estuaries and wetlands during the upper Holocene.*

Cantabria					
Estuary/zone	(1)(x 10^3m^2)	(2) (x 10^3m^2)	(3) (x 10^3m^2)	(4)%	(5)%
T. Mayor	2,130	2,018	492	75.6	55.7
T. Menor	1,729	1,629	1,166	28.4	93.3
S. Vicente	5,509	5,213	3,700	29.0	100.0
Merón	195	138	0	100.0	0.0
Boderna	38	0	0	0.0	0.0
La Rabia	1,666	1,447	763	47.3	70.6
Comillas	73	0	0	0.0	0.0
Luaña	95	76	56	26.3	0.0
S. Martin	5,640	4,665	2,470	47.0	95.9
Pas	4,672	2,265	1,980	12.6	81.7
S. Juan	26	26	20	23.1	100.0
S. Pedro	123	115	115	0.0	0.0
Llamas	495	466	0	100.0	0.0
Santander	45,136	44,467	22,402	49.6	96.0
Galizano	125	115	109	5.6	7.7
Cuberris	139	104	94	9.6	100.0
Ajo	1,541	1,346	1,138	15.4	100.0
Soano	2,270	1,200	290	75.8	100.0
Helgueras	2,240	1,300	100	92.3	100.0
Asón	37,155	30,620	16,311	46.7	77.2
Oriñón	1,500	1,150	350	69.5	100.0
Castro	340	115	10	91.3	100.0
Mioño	47	23	17	26.1	100.0
Ontón	7	0	0	0.0	0.0
Total	113,091	98,498	51,583	47.6	87.6

Basque Country				
Estuary/zone	(1) (x 10^3m^2)	(2) (x 10^3m^2)	(3) (x 10^3m^2)	(4)%
Somorrostro	2,950	2,608	478	81.67
Bilbao	39,592	36,312	25,000	31.15
Plencia	1,108	835	468	43.95
Baquio	539	0	0	0.00
Guernica	11,441	9,953	5,633	43.40
Ondárroa	531	500	134	73.20
Deba	711	610	239	60.81
Zumaya	2,045	1,845	804	56.42
Zarauz	2,500	961	50	94.79
Orio	2,320	1,840	1,200	34.78
S. Sebastián	5,025	3,830	739	80.70
Lequeitio	515	430	368	14.41
Pasajes	2,135	2,110	911	56.82
Total	71,412	61,834	36,024	41.74

(1) Extent during the Flandrian
(2) Extent after the post-Faldrian retreat
(3) Present extent
(4) Percentage of the post-Flandrian extent filled
(5) Percentage of (4) due to direct human action

the productivity of the primary sector (the only one is these areas devoted to agriculture of without use) indicate that both the ecological and the economic productivity would improve considerably by restoring the original intertidal conditions.

An analysis of the predominant economic activities and of the use reclaimed lands were devoted to in each period shows that, although the occupation and use of intertidal and wetland areas has been an important process since the middle of the 19th Century, the driving motivation for it varied a great deal. Thus, several episodes of reclamation can be identified on

Table 2. *Recent historical evolution of the reclamation process in the intertidal and wetland zones of Cantabria (x $10^3 m^2$).*

Estuary/zone	pre-1925	1925-1957	1957-1970	1970-1988
T Mayor	837	14	0	0
T. Menor	380	34	18	0
S. Vicente	1,474	20	8	10
L. Rabia	441	42	0	0
S. Martin	1,580	295	140	90
Pas	233	0	0	0
S. Juan	6	0	0	0
Santander	15,683	2,172	465	2,863
Galizano	0	0	0	0
Cuberris	0	0	10	0
Ajo	208	0	0	0
Soano	910	0	0	0
Helgueras	1,200	0	0	0
Santoña	4,127	4,855	648	1,419
Oriñón	205	440	15	140
Castro	105	0	0	0
Mioño	0	6	0	0
Total	27,389	7,878	1,304	4,552
%	66.6	19.2	3.2	11.0

the basis of the kind of uses established on the new lands which, in turn, were related to the prevailing activities (Figure 6 and Table 4).

The first period, initiated in the 18^{th} Century, corresponds to the filling of limited areas around some towns, for urban uses. During the 18^{th} and the beginning of the 19^{th} Centuries, many enclosures were made for the production of energy, through the construction of tidal mills (mills using tidal currents as a source of energy). These mills seem to have been built mostly at the time when many exports (among them flour) to the American colonies were shipped through the northern Spanish ports (MADOZ, 1850; MAZA, 1965; MERCAPIDE, 1980; CASADO, 1980; AZURMENDI, 1985; BELMONTE *et al.*, 1987). The total area enclosed by the mills (only in Cantabria) amounted to as much as 4 km^2. With an average tidal range of 2.8 m, this represents a potential power of 4–15 $\times$ 10^6 kw h^{-1} $year^{-1}$.

During the second half of the 19^{th} Century, with the decline of this commerce and the gradual substitution of corn crops by dairy farming, many of these mill enclosures started to be drained and devoted to agriculture, and new areas were reclaimed for different types of agricultural uses (pasturelands, fodder crops, forestry). This process of occupation for agricultural purposes was practically stopped by 1925, with the exception of the Ria del Asón.

Towards the end of the last century, many areas (mostly around the Bay of Santander) were used for mining spoil disposal (mainly clay spoil from iron oxide mines). Again, this type of occupation decreased substantially in the twenties, as a result of the decline of mining activities in the region. In the post-war years, especially due to the slow recovery of economic activity in the country which started in the fifties, the reclamation of intertidal and marsh areas was made for the construction of different structures related to transports and commerce (airport, port, roads). Finally, from the seventies onwards, tourism and recreational activities became an increasingly important cause for reclamation; or, in some cases, of filling up of already existing enclosures.

It is interesting to note that the period during which closing of intertidal zones and/or reclamation was most active (1860–1925), coincided with a moderate growth of the population (Figure 6). In the period 1940–1980, when the rate of population growth was significantly greater, the filling activity was less intense. During the period 1970–88 the rate of reclamation has still been important, although in the last few years there has been a growing pressure against reclamation of these zones, as a reflection of the general awareness about their ecological importance. However, there seems to be no significant reduction in the rate of filling.

ASSESSMENT OF SOME ECONOMIC CONSEQUENCES

The value obtained for the biological productivity of the intertidal areas varies depending on the method used for estimates. On the basis of the theoretical food chains 1 to 3 mentioned above, the productivity would vary roughly from \$US 2,000 to 100,000 km^{-2} $year^{-1}$.

The first chain would produce 163 kg of fish per square kilometer every year, at a market price of \$US 13 kg^{-1}; that is, a potential productivity of \$US 2,120 km^{-2} $year^{-1}$. The second chain would yield about 43,000 kg of fish, at \$US 2.5 kg^{-1}, or some \$US 100,000 km^{-2} $year^{-1}$. Finally, the third chain would yield about 40,000 kg of mussels, at \$US 1 kg^{-1}, equivalent to \$US 40,000 km^{-2} $year^{-1}$ (CENDRERO *et al.*, 1981). The figures derived from the productivity values given by GUNNERSON (1963) would be about three times higher.

Table 3. *Present land-uses in the areas created after the post-Flandrian retreat (x $10^3 m^2$)*

	Cantabria						
Estuary/zone	(1)	(2)	(3)	(4)	(5)	(6)	(7)
T. Mayor	804	237	45	48	10	374	8
T. Menor	(+)414	0	0	0	0	18	31
S. Vicente	1,384	63	9	39	0	18	0
Merón	0	0	0	2	0	123	13
La Rabia	198	0	0	5	10	376	95
Luaña	0	0	0	7	13	0	0
S. Martin	420	250	820	20	30	635	20
Pas	103	0	0	0	0	130	52
S. Juan	0	0	0	0	0	6	0
Llamas	15	253	0	0	0	198	0
Santander	9,162	1,153	3,287	4,592	1,077	2,185	609
Galizano	0	0	0	5	0	2	0
Cuberris	0	0	0	0	5	5	0
Ajo	19	0	0	0	0	189	0
Soano	554	0	0	0	90	266	0
Helgueras	520	90	0	0	50	540	0
Asón	7,317	2,725	275	180	0	3,332	480
Oriñón	475	0	0	0	0	325	0
Castro	0	105	0	0	0	0	0
Mioño	3	3	0	0	0	0	0
Total (x $10^3 m^2$)	21,388	4,879	4,436	4,898	1,285	8,722	1,308
%	45.6	10.4	9.4	10.4	2.7	18.6	2.8

(1) Agriculture and forestry, (2) Urban, (3) Industrial, (4) Transports and ports, (5) Others, (6) Without use, (7) Dunes.
(+) Mariculture.

	Basque Country				
Estuary/zone	(1)	(2)	(3)	(4)	(5)
Somorrostro	332	0	1,413	0	385
Bilbao	0	1,050	9,462	800	0
Plencia	190	67	0	0	110
Guernica	2,938	0	0	0	1,382
Ondarroa	55	125	85	101	0
Deba	220	140	0	11	0
Zumaya	400	406	235	0	0
Zarauz	175	300	101	0	355
Orio	455	85	100	0	0
S. Sebastián	0	2,779	0	312	0
Lequeitio	0	0	0	23	39
Pasajes	0	364	267	443	125
Total (x $10^3 m^2$)	4,765	5,316	11,663	1,690	2,376
%	18.5	20.6	45.2	6.5	9.2

(1) Agriculture and forestry, (2) Urban, (3) Industrial, (4) Others, (5) Without use.

The actual clam productivity observed in the area controlled by the Spanish Institute of Oceanography is equivalent to $US 612,000 year. If the productivity for the reclaimed areas were only half that figure and only half of such areas were productive, the average productivity would be $US 153,000 km^{-2} $year^{-1}$.

This figure can be compared with the productivity that can be obtained in areas subject to normal techniques of aquaculture (FERNANDEZ PATO, *personal communication*) which is, in the region, of the order of 200,000 kg km^{-2} $year^{-1}$ or $US 3,600,000 km^{-2} $year^{-1}$. This represents a theoretical potential productivity, not an actual production of the areas affected. This productivity would probably not be obtained in all the areas which were subject to reclamation.

There are no available figures about actual

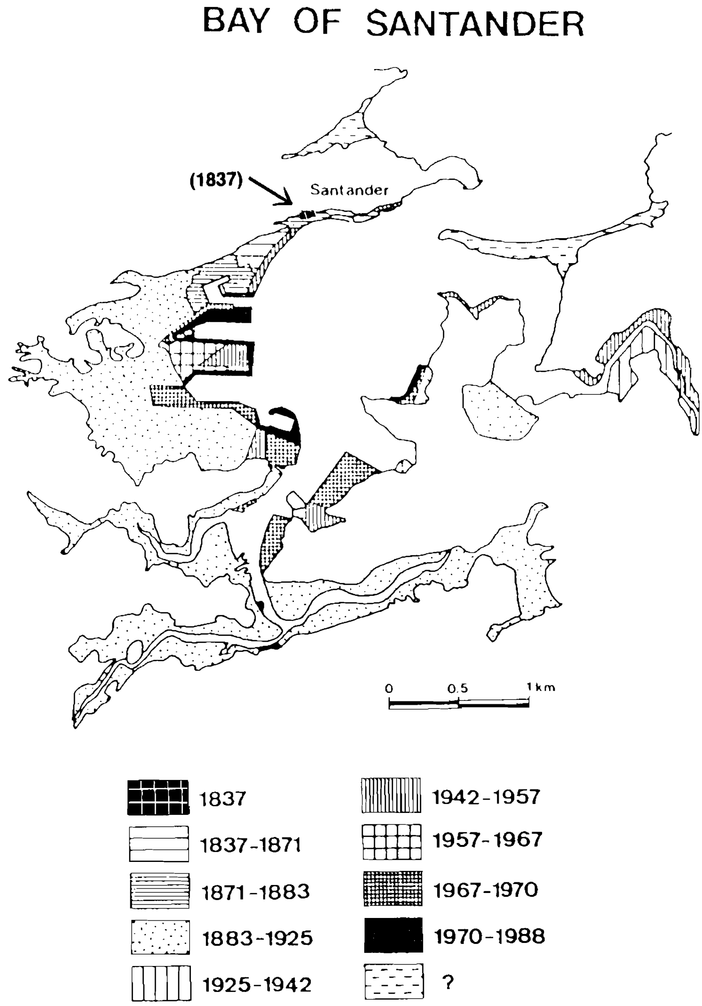

Figure 2. Evolution of the reclamation process in the Bay of Santander.

productivity, by surface unit, of other species, although it seems reasonable to assume that all of them together represent at least as much as clams. Thus, the economic value of the biological productivity expressed in terms of products obtained by the primary sector is about $US 306,000 km^2 $year^{-1}$. This average figure is obtained assuming that half the reclaimed areas would be productive and that their productivity (in clams) would be equivalent to 50% of the productivity actually observed in the controlled area, and adding a similar amount for the value of all other species of commercial interest.

The biological productivity of reclaimed areas devoted to agricultural uses has been calculated in terms of the value of their produce, which in the case of this region is practically only milk. The average figure of 33 cows km^{-2} gives an average value of $US 40,000 km^{-2} $year^{-1}$ in milk production. The difference between this figure and the former one is $US 266,000 km^{-2} $year^{-1}$.

The natural intertidal areas, where products are obtained by fishing or shellfish harvesting, can be transformed into farming areas (either dairy farming or aquaculture farming). The data presented suggest that the brute yield in

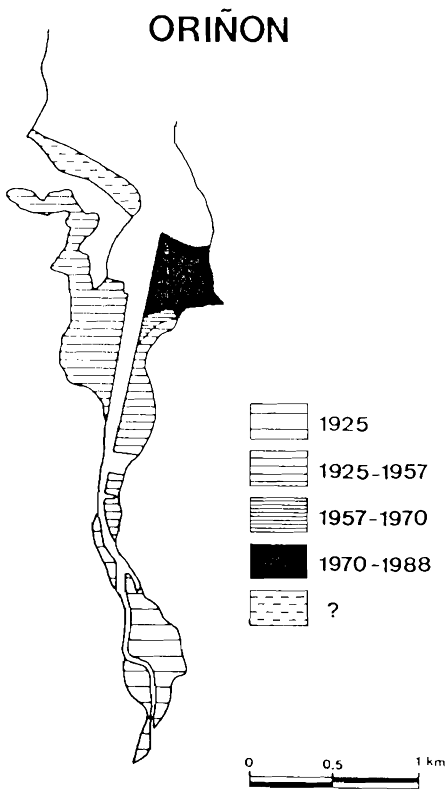

Figure 3. Evolution of the reclamation process in the "Ria de Oriñón."

the latter case would be higher. However, we have not attempted to compare the necessary initial investment in both cases.

Out of the 64 km^2 of intertidal and wetland areas subject to reclamation, about 58% have been devoted to agriculture (26 km^2) or to no specific use (11 km^2). That is, their productivity is obtained basically through the primary sector. For these areas, the biological productivity expressed in terms of the products actually obtained has decreased, as compared with the actual productivity of natural estuarine areas. The decrease can be estimated as approximately \$US 266,000 km^{-2} year^{-1}, or \$US 9.84 $\times$ 10^6 per year for the 37 km^2 affected.

It is a well known fact that fish catches in the Bay of Biscay have experienced a considerable reduction in the last decades, despite the increased "fishing effort." It is difficult to know to what extent this shortfall is due to the reduction of the essential breeding and feeding intertidal and marsh zones, to pollution, or to overfishing.

The results obtained through a public opinion survey carried out in the Santander area (CENDRERO *et al.*, 1981) about the "willingness to pay" among the population, to maintain the aesthetic quality and recreational potential of the estuarine zones yielded an average figure (corrected for inflation) of \$US 217 per person per year.

Taking only half of that figure (about \$US 100) as an average for the whole population of the coastal region considered (some 2,000,000 people), the total theoretical figure the population would be "willing to pay" to maintain the aesthetic and recreational qualities of intertidal and wetland zones would be in the order of \$US 200 $\times$ 10^6 year^{-1}.

The "aesthetic and recreational productivity" is not comparable to fishing or agricultural productivity, directly derived from biological productivity. Rather, it only represents a theoretical estimate of the value that inhabitants of the area attribute to the possibility of using intertidal and wetland areas. This value, even with the conservative assumptions presented above, seems to be high. If not only inhabitants, but domestic and foreign tourists as well were included, the figure would be significantly higher.

This assessment of the economic consequences of reclamation must be considered only as a first approximation. First of all, the comparison presented between unreclaimed and reclaimed areas is significant only for reclaimed lands devoted to agricultural or similar uses (about 58%). Second, there are several assumptions with a large margin of error and some of the measurements of the magnitudes taken as a basis for the calculations (biological productivity, willingness to pay) were made only in a few places and then extrapolated to the whole region. Moreover, there are other aspects of the reclamation process with economic significance, for instance increased pollution and sedimentation in estuaries, as a result of their reduction in volume, reduction in waterfowl, *etc.*, which have not been estimated, because of the lack of data.

Although the figures presented here are rough and must be taken with caution, it appears that the substitution of intertidal and wetland areas by agricultural lands implies a

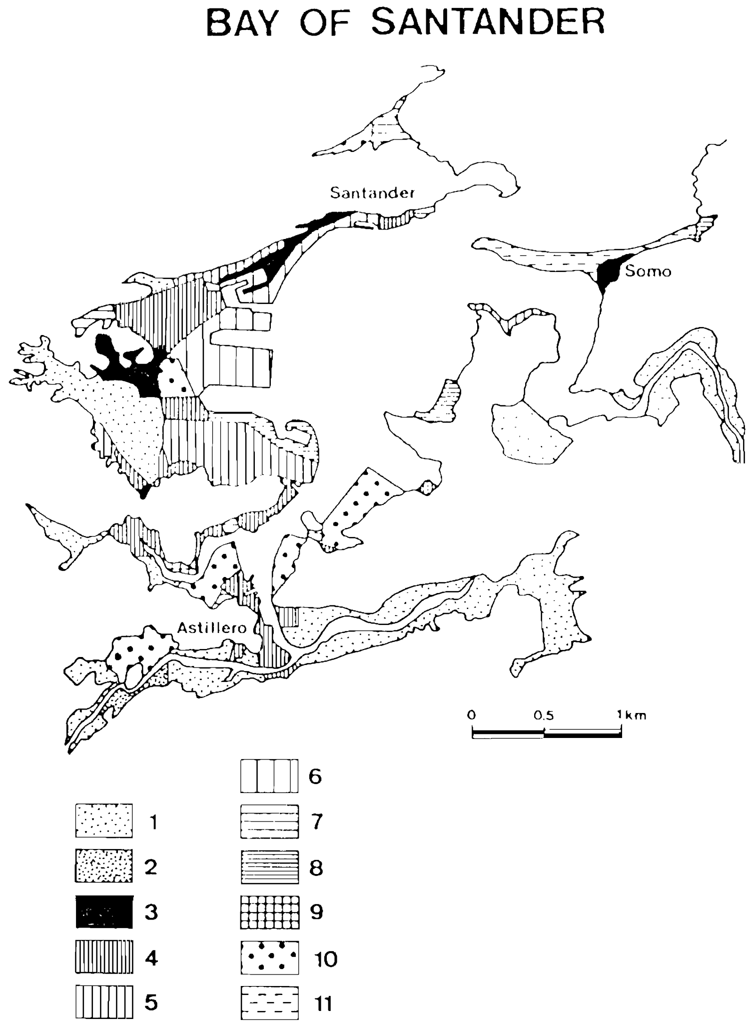

Figure 4. Present uses of reclaimed lands in the Bay of Santander. (1) agriculture; (2) forestry; (3) urban; (4) industrial; (5) transport; (6) port; (7) institutional buildings; (8) recreation; (9) urban waste disposal; (10) without use; (11) dunes.

loss in biological productivity (which can be expressed in terms of products with a market value) and also a loss in qualities related to recreation, to which the present population attribute a considerable value.

In the case of activities such as urban, industrial, transport, etc. the comparison is not so clear, as the primary productivity expressed in fish produce cannot be compared in simple terms with the productivity derived from such activities. In order to apply to these areas the kind of analysis presented above, it will be assumed that the non-agricultural activities implanted on reclaimed lands would have been installed in other, already existing agricultural lands in the vicinity of estuaries. There are, in all cases, wide areas of this kind. This theoretical situation would imply that the productivity of former intertidal and wetland areas presently occupied by industry, housing, *etc.*, would be maintained, and that an equivalent surface of agricultural lands would have disappeared. The comparison presented above would then be applicable.

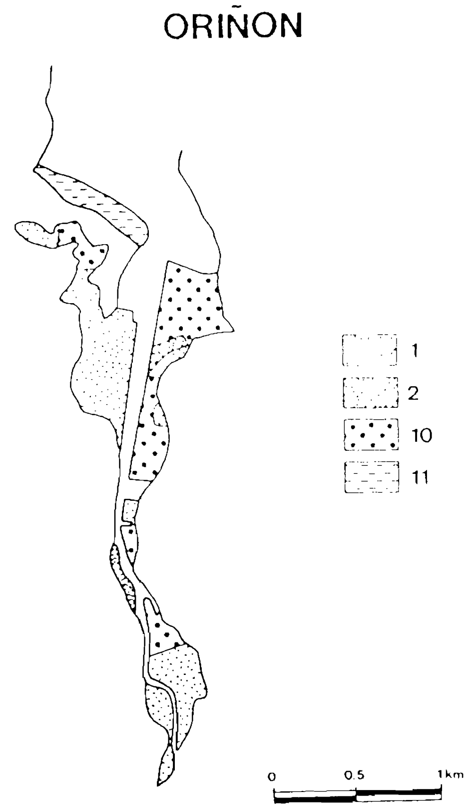

Figure 5. Present uses of reclaimed lands in the estuary of Oriñón. (1) agriculture; (2) forestry; (10) without use; (11) dunes.

The occupation of public reclaimed lands is usually made through leases and it is cheaper than the acquisition of agricultural lands from their owners. This is one of the incentives offered to companies for the establishment of new industries, *etc.*

In the light of the estimates presented above it is suggested that, from the point of view of society, it would perhaps be more "economical" to devote public funds to subsidize the purchase of such lands, instead of subsidizing through leases for reclamation. The existing industries and services would be there in both situations, but the productivity of coastal areas, in biological and recreational terms, would be better preserved in the first case.

Certain activities, however, would have no reasonable alternative (port installations, some roads, airport) and they should be installed on reclaimed lands, but these account for no more than 15% of the total.

Changing the present emplacement of activities such as industry, urban, etc. is probably not a realistic possibility. However, as much as 51% of the reclaimed surface corresponds to areas which have been simply isolated or drained, but with no filling, and are presently devoted to agriculture or without use (some of the filled areas are also devoted to agriculture or have no use, making a total of 58% for these categories). In this case, the physical action needed to restore the original situation has a very low cost. Simply breaking up a series of openings in the artificial enclosures of loose materials would enable the penetration of tidal waters and the re-establishment of the intertidal or wetland environment. Past experiences indicate, as mentioned above, that the recovery of natural conditions can take place in a few years. The main cost of this operation would be represented by the purchase of land or of lease rights from the present owners. The average price of land in these areas, \$US 20–40 m^{-2} (figure obtained from real state agents, on the basis of recent land purchases), and the average value of the structures they contain is \$US 7–9 $\times 10^6$ km^{-2} (figure obtained through sample counting of buildings and other installations, on air photographs and multiplying by the average value). Therefore, the cost of such operation could be estimated about \$US 27–49 $\times$ 10^6 km^{-2}. To what extent society would be willing to allocate these financial resources in order to improve the biological productivity and the environmental quality of coastal areas is something that should be determined.

IMPLICATIONS OF SEA-LEVEL RISE

But the reclamation and occupation of intertidal and marsh zones also represent a risk which must be carefully considered and assessed, in the light of the present data about climatic change and sea-level rise (BARTH and TITUS, 1984; TITUS, 1986; THOMAS, 1986; BRUUN, 1986, 1988; SMYTH and JENNINGS, 1988; FAIRBRIDGE, 1989; PIRAZZOLI, 1989; SCHNACK and PIRAZZOLI, 1990). According to different models proposed, this rise could very well reach 1 m towards the middle of the next century.

The consequences, for this region, of an even-

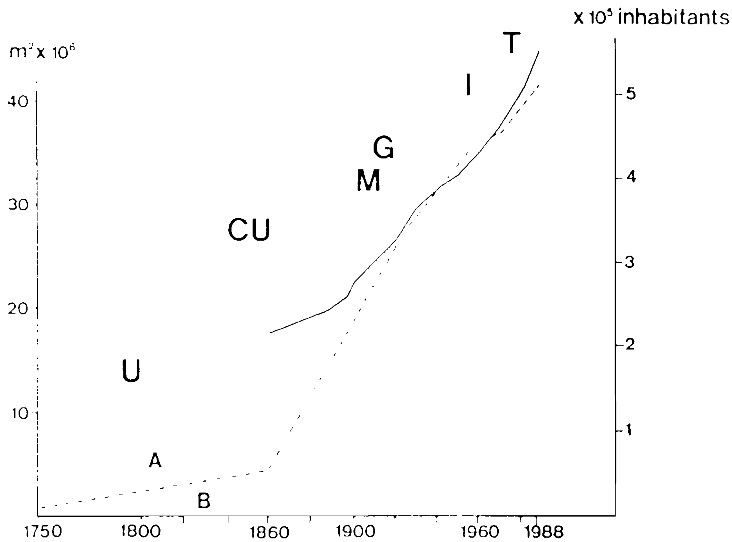

Figure 6. Comparison between the demographic evolution (continuous line) and the filling of intertidal and wetland areas (dotted lines) in Cantabria. A and B correspond to two different possibilities, determined by the lack of precision of some old maps. (U) Urban (CU) period of development of commerce with the Americas, (M) development of iron mining, (G) development of dairy farming, (I) development of industrial and transport facilities, (T) tourism.

Table 4. *Evolution of reclamation in Cantabria, in relation with the evolution of economic activities.*

Periods	pre-1800	1800-1860	1860-1925	1925-1957	1957-1970	1970-1988
Main activity	commerce	commerce	agriculture mining industry	industry	industry infrastructure	tourism
Predominant use of reclaimed land	urban	tidal mills	pasture, crops mining spoil industry	industry	port, roads airport	recreation residential
Area (m^2)	approx. 2500000	approx. 2300000	22589000	7878000	1304000	452000

tual rise in sea-level have been assessed in terms of the capital value of structures which would be in a risk situation. A rise of about 1 m would affect the areas formed after the post-Flandrian retreat (73 km^2).

If no defensive actions are taken, the value (conservative estimates) of buildings, streets, *etc.* would be $US 2,640 $\times$ 10^6; the value of industrial installations $US 1,127 $\times$ 10^6; ports, airport, roads, *etc.* 650 $\times$ 10^6; various services and utilities $US 390 $\times$ 10^6; agricultural installations $US 104 $\times$ 10^6. The total would be about $US 4,911 $\times$ 10^6.

In order to be prepared for that eventual situation, several alternatives could be considered. The first one would obviously be to "let nature follow its course" (GIBBS, 1986; BRUUN, 1988). In this case the losses would be partly compensated by the recovery of the non built-up areas (37 km^2) which would be again part of the estuarine and coastal wetlands environments, with the consequent increase in biological productivity. Plans for the gradual abandonment of potentially affected areas and substitution of the buildings and structures in them would be necessary.

A second alternative would be to protect all hazard zones and to maintain them in their present condition. This would require the construction of sea walls of different types around the coastal perimeter (171 km only in Cantabria) as well as the installation of systems to pump water in order to maintain the present water table; that is, a Dutch kind of solution. The cost of sea walls varies, depending on the type of terrain and the intensity of wave attack, but it would probably be in the order of tens of millions of dollars, a small proportion of the value to be protected. The cost of the system to maintain the water table is much more difficult to calculate, and it has not been estimated. It would, in all certainty, be considerable.

A third, probably more reasonable alternative, would be to abandon certain zones and to defend others, either by sea-walls and water pumping systems, or simply by raising the surface with additional fill material. This solution would doubtless be the most economical for things such as roads, railroads, airport runways, *etc.* In built-up areas, it would normally imply the prior demolition of existing buildings. Considering that most buildings, either industrial or residential, have a limited "useful life," this, again, would probably be the most sensible alternative in many cases. The evaluation—even in a rough way—of the cost of this alternative would require a much more detailed analysis—not undertaken so far—to determine which zones should be preserved and which kind of solution would be most advisable in each case.

It is clear, however, that the risk represented in the region by an eventual rise in sea level could affect as many as 73 km^2 of land, and that it would imply important economic consequences. Adaptation and adjustment to this kind of high-risk, high-uncertainty situation requires careful analysis and planning (FAIRBRIDGE, 1989), including the consideration of different scenarios and alternatives, and the comparative evaluation of them in economic, environmental and social terms.

The in-depth analysis and evaluation of existing alternatives should be undertaken as soon as possible. Decisions must allow for sufficient time to allocate capital resources and to put into practice the measures (physical, legal and financial) required.

CONCLUSIONS

In summary, it can be concluded that, in the eastern part of the Bay of Biscay, the process of surface accretion due to human activities in recent times (about 150 years), has contributed to the creation of 64 km^2 of new land spaces, with the consequent reduction of estuarine and wetland areas, which are generally recognized as essential from the ecological point of view because of their high biological productivity and their importance as breeding grounds for many species (PARK, 1980; FOURNEAU, 1982; CHARLIER, 1987; PEREZ and CANTERAS, 1990).

The rate of this artificial process is 114 to 186 times greater than the one due to natural causes, and it represents, by far, the main factor in the geomorphological evolution of the coastline. The rate of the process was highest in the period 1860–1925, but it is still important. In some areas (Bilbao, Pasajes), the intertidal zones have been totally occupied and only the permanently submerged port and navigation areas remain. If the recent rates (1970–1988) of reclamation are maintained, the remaining intertidal zones and coastal wetlands could practically disappear towards the end of next century. Of course, their disappearance from the ecological point of view would happen before that, because the activities related to reclamation would severely damage the ecosystems before their total disappearance, as can be seen nowadays in many of the estuaries.

The historical development of the process shows a series of episodes which can be correlated with the change in economic activities in the region. To a very great extent, the areas reclaimed have been devoted to low productivity uses from the biological point of view. About 58% of the reclaimed lands have been devoted to agriculture or remain without specific use. These areas have a biological productivity lower than the one of the original intertidal areas. When this productivity is expressed in terms of the value of the products obtained by the primary sector in both cases, it appears that the present situation implies a loss in productivity of the order of \$US 250,000 km^{-2} $year^{-1}$, or nearly \$US 10×10^6 per year for the whole area. That is, the decrease in biological productivity also implies a decrease in the monetary values obtained.

The appreciation of the value of these intertidal areas for aesthetic and recreational use by the population can be estimated around \$US 200×10^6 per year. This is a theoretical "potential loss," not comparable to the actual loss in productivity mentioned above.

The recovery of 51% of the reclaimed areas, for the restoration of natural coastal environments, would require very limited physical action, although it remains to be seen to what extent society would be willing to devote the necessary financial resources (\$US 27–49 $\times 10^6$) for such an effort.

An eventual rise in sea level would endanger the 73 km^2 of new natural and artificial lands. The capital value of the buildings, infrastructures, *etc.* in this area is of the order of \$US 5,000 $\times 10^6$.

Several alternatives to cope with this problem are possible. It seems that the most advisable solution would be to let nature recover part of the estuarine environments lost, and to plan in advance for the gradual withdrawal from the endangered areas and the selective protection and/or substitution of certain buildings and installations. In any event, it would be reasonable to refrain from establishing new installations in these hazards areas.

This kind of planning requires in-depth analysis for the comparison of different solutions for each specific zone, in order to plan with sufficient time the actions to be taken. In view of the existing evidence about sea level rise, these analyses must be undertaken soon.

The overall consideration of the historical process and the present situation suggests that, although the reclamation of coastlands for agriculture might have been economically reasonable in the past, when dairy products were much more valuable in the region than fish and shellfish, this is not so at present. Also, the change in social values has increased very considerably the importance of aesthetic and recreational resources, which had very little social and economic relevance only a few decades ago. Both factors, together with the well-established fact that intertidal and wetland areas of the temperate zones are among the ecosystems with the highest biological productivity, indicate that the reclamation of new areas would probably not be advisable, especially in a region where there are wide spaces available for the siting of new human activities.

Moreover, the existing evidence about sea level rise shows that these reclaimed lands constitute high hazard zones, whose protection is likely to be costly. It would therefore be reasonable to avoid the need of new protection works, by siting all new structures outside the areas likely to be affected by a rise in ocean level.

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□ RÉSUMÉ □

Au moyen de photos aériennes, de cartes anciennes et d'observations de terrain, analyse l'évolution post flandrienne des zones estuariennes ou humides comprises entre la Deva et la Bidassoa, en vue de quantifier le développement historique des aménagements dans cette zone et d'évaluer certaines conséquences sur l'environnement et l'économie. L'ensemble de la zone émergée au retrait post flandrien couvre environ 24 km^2. Les nouvelles terres formées ensuite couvrent 73 km^2. Environ 64 km^2 sont estimés dûs à l'intervention humaine (draînage, comblement, assainissement). Cette zone artificielle reprèsente 40% des zones comprenant estuaires et terres humides. Supposant un taux d'accrétion uniforme, il apparaît que de nouvelles terres se sont formées selon un processus naturel à la vitesse de 0.22 km^2 par siècle après le retrait flandrien. La répartition des types d'utilisation du sol dans les terres créées artificiellement sont 36%—agriculture, 22%—industrie, 14%—résidentiel, 13%—autres, et 15%—non utilisé. Une comparaison estimée à partir de la productivité biologique en terme de valeur monétaire des produits obtenus par le secteur primaire montre que la substitution des zones interidales ou humides à l'agriculture représente à l'heure actuelle une perte de 250.000$ par km^2 et par an. Cette substitution affecte 58% des terres aménagées. Une estimation de "l'acceptation à payer" de la population pour la sauvegarde des qualités esthétiques et du potentiel récréatif de ces zones indique que la population évalue cette ressource à 200 milliards de dollars par an. Les zones comblées sont dans l'ensemble à moins de 1 m en dessous du niveau de la mer, aussi une montée du niveau de la mer d'environ 1 m, telle que prédite par plusieurs modèles pour les siècles à venir, mettrait en péril 73 km^2 des terrains post flandriens naturels et artificiels. La valeur en capital des immeubles, structures, *etc.* ont été estimés à environ 5,000 milliards de dollars.—*Catherine Bressolier-Bousquet, Géomorphologie EPHE, Montrouge, France.*

□ ZUSAMMENFASSUNG □

Die Entwicklung von Ästuar- und Feuchtgebieten nach dem Flandrischen Maximum in den Küstenzonen im Sektor zwischen den Flüssen Deva und Bidasoa ist mit Hilfe von Luftbildern, alten Karten und Seekarten sowie Geländebeobachtungen analysiert worden. Diese Studie hatte die Ziele, die geschichtliche Entwicklung des Landgewinnungsprozesses in diesem Gebiet zu quantifizieren und daraus einige Umwelt- und ökonomische Konsequenzen abzuleiten. Das gesamte Gebiet, das während des Post-Flandrischen Meeresspiegelrückganges auftauchte, war annähernd 24 km^2 groß. Die Neulandbildung danach bedeckte ca. 73 km^2. Von diesen sind ungefähr 64 km^2 durch menschlichen Einfluß entstanden (Drainage, Auffüllung und Landgewinnung). Diese künstlich geschaffene Fläche repräsentiert 40% der Ästuarund Feuchtgebiete. Von einer gleichförmigen Zuwachsrate (eine deutliche Vereinfachung) ausgehend, scheint es, daß Neulandgebiete durch natürliche Prozesse in einer Größe von ungefähr 0.22 km^2/Jahrhundert nach dem Flandrischen Meeresspiegelrückgang geformt wurden. Die ungefähre Verteilung von Landnutzungstypen in den künstlich geschaffenen Gebieten ist: 36% Landwirtschaft, 22% Industrie, 14% Wohngebiete, 13% andere und 15% ohne Nutzung. Eine vergleichende Einschätzung der biologischen Produktivität, ausgedrückt durch den monetären Wert der Produkte, der im Primärsektor erzielt wird, zeigt, daß der Ersatz von Überflutungs- oder Feuchtgebieten durch Agrarland zur Zeit einen Verlust von über US $250,000 km^{-2} Jahr^{-1} darstellt. Dieser Ersatz betrifft 58% des neugewonnenen Landes. Eine Schätzung über die "Zahlungsbereitschaft" der Bevölkerung, die ästhetischen Qualitäten und Erholungspotentiale dieser Gebiete zu erhalten, zeigt, daß die Bevölkerung dieser Region den Wert dieser Neuländer mit ungefähr US $200 $\times$ 10^6 pro Jahr einschätzt. Die aufgefüllten Gebiete sind im ganzen weniger als 1 m über dem Meeresspiegel. Deshalb würde ein Meeresspiegelanstieg von über 1 m, wie er in mehreren Szenarien für die nächsten Jahrhunderte vorhergesagt wird, 73 km^2 des Post-Flandrischen natürlichen und künstlichen Landes gefährden. Der Kapitalwert von Gebäuden, Strukturen, etc. auf diesem Land ist auf rund US $5,000 $\times$ 10^6 geschätzt worden.—*Gabriele Lischewski, Essen, FRG.*