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The Geomorphological and Botanical Changes in Kernic Bay (Brittany, France): Influence on Coastal Management

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ABSTRACT

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Kernic Bay, located on the northern coast of Brittany, is a coastal spot of great touristic but also economic interest as until recently, seasonal sand removal has prevented the natural filling of the bay through sedimentation. Due to the cessation of sediment removal, and the recent appearance of *Spartina anglica*, drastic changes occured with a continuous elevation of the substrate level and a subsequent reduction in the tidal volume. This paper outlines the sedimentological and hydrodynamic conditions of the Kernic lagoon and the chronological events leading up to the present status of the site. Of particular importance is the impact of *Spartina anglica* in the inner parts of the bay. The interferences between these processes are discussed in relation with the project of local authorities to develop an international windsurf base in the bay. Several methods of *Spartina anglica* eradication are proposed.

ADDITIONAL INDEX WORDS: *Sediment-accretion, tidal level* spartina anglica *spread, coastal geomorphology, coastal management.*

INTRODUCTION

The Kernic Bay (4°W, 48° 40′N), on the northern coast of Brittany (France), is a small lagoon opening into the English Channel through a narrow inlet between the head of a sand spit and a rocky point. Kernic Bay is used as a tourist site and is subject to rapid changes linked to the deposition of the lagoon with sand and silt and the spread of *Spartina anglica* C.E. Hubbard (BONNOT-COURTOIS *et al.*, 1989; LEVASSEUR and GUÉNÉGOU, 1988). Until 1984, sandy material extraction used in field development controlled the silting in the bay. However, recent environmental controls have restricted the removal of sand, resulting in a deterioration of the lagoon.

The aim of this paper is to describe the hydrodynamic and sedimentological conditions, in association with a chronological study of the spread of *Spartina anglica*. These data allow the prediction of spread of the halophytic vegetation and a consideration of suitable management for the development of a windsurf base.

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GEOMORPHOLOGY AND SEDIMENTOLOGY

The Kernic Bay is a flat tidal lagoon separated from the open sea by a sand spit formed by an eastbound longshore current and covered by dunes. Only strong tidal currents are able to maintain communication between the sea and the lagoon through a single and narrow inlet (LAFOND, 1988; LAFOND *et al.*, 1989). The lagoon empties completely at low tide and a 200 ha area is covered during spring tide (Figure 1).

In the 19th Century, the Kernic Bay was wider, with the building of sea walls in 1828 and 1849 for land reclamation, the area was reduced. Fresh water flows into the bay from two small rivers, the Kerallé and the Frout, coming from a catchment area of 55.1 km^2. The fresh water supply not only reduces the bay sal-

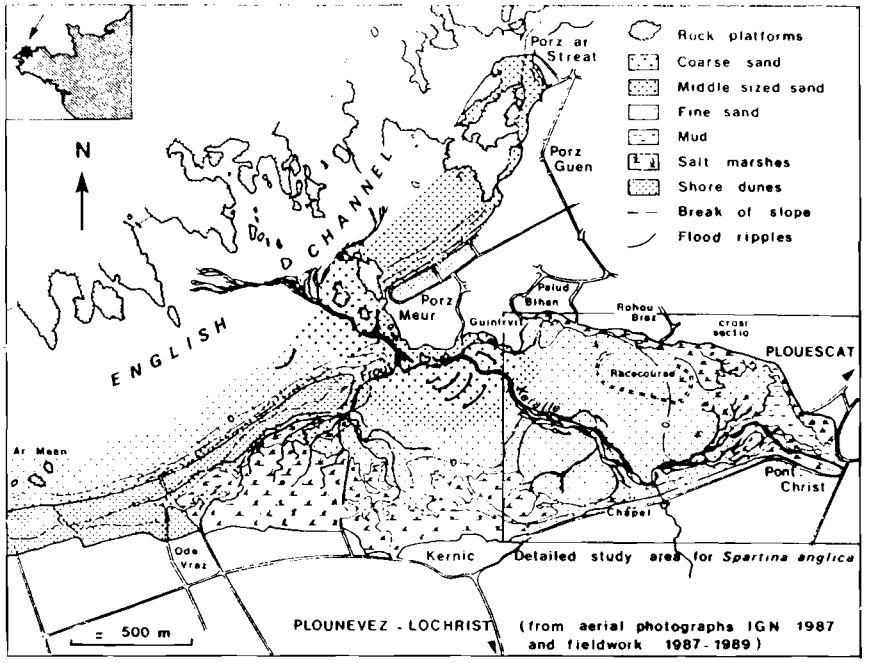

Figure 1. Geomorphology and Sedimentology of the Kernic Bay. (See Figure 4 for detailed sites for *Spartina anglica* development.)

inity, but also produces a mudflat through silt deposition in protected zones, carrying chemical fertilizers and organic matter from the cultivated fields.

At spring tide, the tidal range reaches 9 m, but is only 2 m in neap tide; sediment from tidal currents is estimated annually to be about 30,000 m^3, which results in progressive filling of the lagoon at a mean rate of 2 cm per year (TIETZE, 1979; TIETZE *et al.*, 1979).

A marsh vegetation, mainly *Puccinellia maritima* (Huds.) Parl. and *Halimione portulacoides* Aellen, is well developed in the inner parts of the bay. The eastern and southwestern edges, protected by the sand spit, were almost fully colonized between 1966 and 1988 by *Spartina anglica* (LEVASSEUR and GUÉNÉGOU, 1988).

Sediments have been sampled from the outer beach as well as from the different areas of the lagoon. They are made of coarse and fine sands, silt and mud, and show a specific grain-size distribution (BONNOT-COURTOIS *et al.*, 1989). The outer shoreline is exposed to the dominant NW waves, which are diffracted in tiny crests close to the shore producing an irregular longshore current. This current results in sand drifting towards the head of the spit and the inlet. Grain-size varies from fine sand close to the dune (d50 = 200 to 250 μm) to shelly gravels mixed with a fine grey sand (d50 = 150 to 200 μm) on the lower part of the beach (Figure 2).

Tidal currents up to 3 m/s occur inside the inlet where only coarse material (d50 = 400 μm) is deposited. Deltas occur inside and outside the lagoon due to flood and ebb currents. Both deltas are unstable so that up to 1 m of the surface migrates during spring tides. The grain size decreases to 230 μm in the inner part of the flood delta.

The innermost parts of the bay have fine sands and silty sediments (d50 < 100 μm) with 10 to 20% of mud (d < 40 μm) in the areas where halophytic vegetation grows (Figure 2). The deposition of very fine-grained sediments allows the colonization of *Spartina anglica*, with the existence of vegetation slowing down the currents and thus increasing the sedimentation rate.

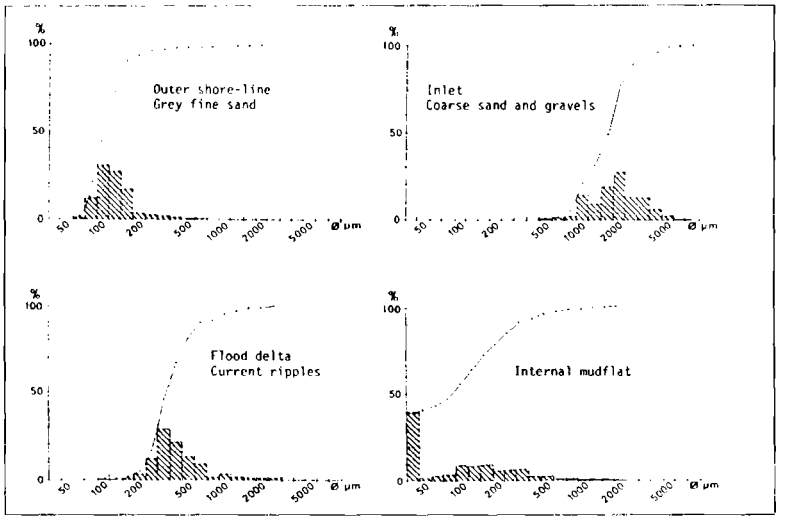

Figure 2. Grain-size distribution in the main sedimentary facies of Kernic Bay, expressed in frequency histograms and cumulative curves.

The spread of *Spartina anglica* is related to the different sedimentological environments (BONNOT-COURTOIS *et al.*, 1989). Presence of coarse material and instability of the substrate in the inlet and the flood delta prevents establishment. On the other hand, the internal protected zones consist of fine, stable deposits where growth is rapid.

SPARTINA ANGLICA SALTMARSHES

Spartina anglica (Townsend's cord-grass) appeared in the late 1800s in England. It is an amphidiploid plant, probably arising from a cross between the Afro-European species *S. maritima* (Curt.) Fern. and the North American one *S. alterniflora* Lois. (MARCHANT, 1968). This vigorous hybrid, occurring since 1906 in France, is now found throughout northern France. It was first noticed near the site in 1970, but probably occurred in Kernic Bay since 1966 (GUÉNÉGOU and LEVASSEUR, 1988). In the original saltmarsh, *Halimione portulacoides* occurred on ancient sand dunes, associated with *Puccinellia maritima* on the dune margins. *Scirpus maritimus* L. or *Juncus maritimus* Lam. occurred on the mud. Outside the saltmarsh, algal deposits and populations of annual *Salicornia* species grew sporadically on the mobile sand.

The invasion of coastal areas by *Spartina anglica* was studied in Great Britain (e.g., CHATER and JONES, 1957; GOODMAN, 1960; GOODMAN *et al.*, 1959; GOODMAN, 1960; RANWELL and DOWNING, 1960; BIRD and RANWELL, 1964; RANWELL, 1964, 1967; GOODMAN *et al.*, 1969), and in New Zealand (LEE and PARTRIDGE, 1983), China (CHUNG-HSIN, 1985), and France (JACQUET, 1949; GUÉNÉGOU, 1986; GUÉNÉGOU and LEVASSEUR, 1988).

The species reproduces sexually with production of seeds, and asexually by the formation of "tussocks" from rhizomes development (GOODMAN *et al.*, 1969). *Spartina anglica* tends to be the first to colonize bare flats in front of existing saltmarshes. This species also migrates into older saltmarshes via tidal creeks and deplaces the original vegetation. Tussock growth is rapid, the clones lose their individual identity and soon merge together, giving rise to a sward (Figure 3).

A north-south transect and several sites (A-J) have been studied in Kernic Bay with regard to vegetation (Figure 4). *Spartina anglica* occupies a vertical range of 1.10 m (mean = 0.8 m) in the lagoon (Figure 5) occurring on substrates varying from mud in the east (Pont-Christ) to sand in the west. The grain-size distribution varies from 60% of particles < 50 µm to 80% of

Figure 3. Kernic Bay. At the foreground, isolated patches of rather old *Spartina anglica* showing clonal extension. At the background, first stage of coalescence giving rise to a sward.

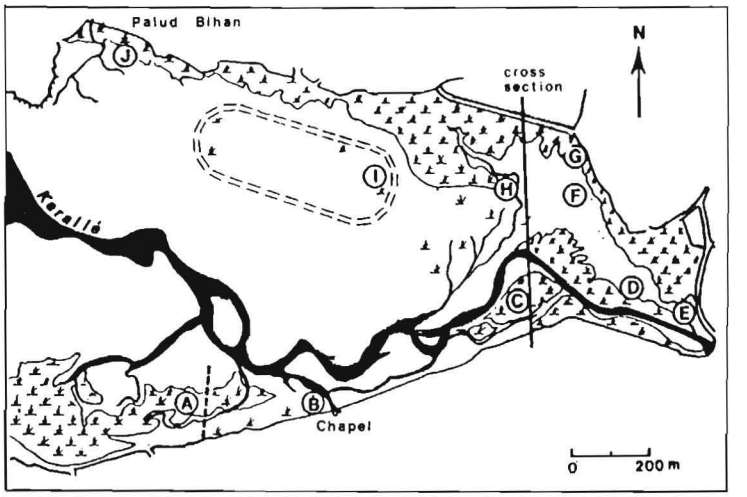

Figure 4. Localisation of the different sites studied in the inner par of the Kernic Bay for *Spartina anglica* development.

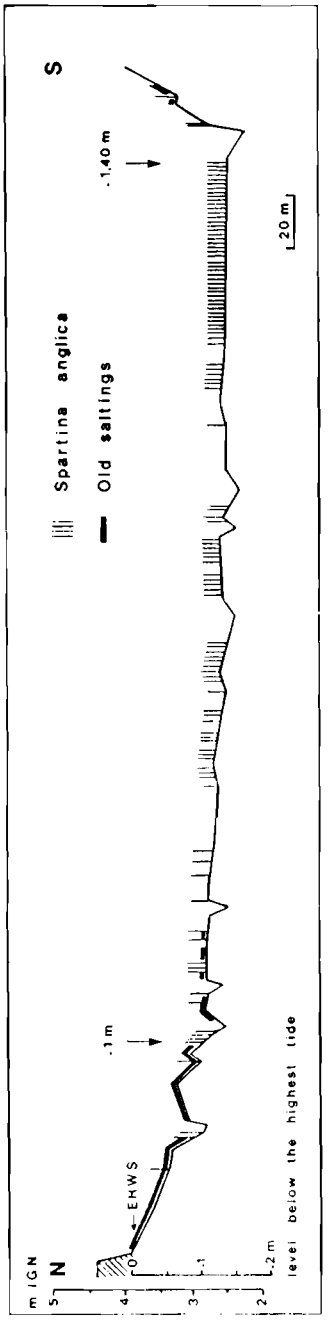

Figure 5. Cross section of the inner zone of the Kernic Bay, showing *Spartina anglica* distribution. (See Figure 4 for the localisation of the cross section.)

middle-sized sand associated with 15 to 20% of fine-grained sediment. Seed germination occurs near fresh water streams, commonly where ground water seepages occur and the substrate is stable and moist.

The mean growth rate of *Spartina anglica* in Kernic Bay is about 15 cm/year based on the increase of the surface of the existing implantations and the age of isolated patches (Table 1). GOODMAN *et al.* (1969) reported rhizome growth of 13.4 cm/year on sand and 33.8 cm/year on mud.

The sediment accretion rate varies here from 5 to 15 mm/year (Table 1). Accretion rates found by RANWELL (1964a) varied from 5-10 mm/year to 2.6-10.2 mm/year in England. LEE and PARTRIDGE (1983) noted rates of mud deposition between 3 and 12 mm/year.

Sediments can affect the stem growth and the productivity (Table 2), either in the case of too fine-grained material (site E, Figure 4) or too coarse material (site B, Figure 4). In contrast, fresh water increases plant height (sites F, G, and J, Figure 4) in well-drained soils. Strong tidal currents or higher salinity and sand mobility prevent or reduce the plant growth (sites A and B, Figure 4). In sites where coarse and wave action is high, dwarf growth forms occur (CALDWELL, 1957). When the soil is too muddy (site G, Figure 4) and the drainage pattern inadequate, *Spartina anglica* does not develop.

Before 1966 (Figure 6A, Top), the saltmarsh occurred on the north and east sides of the inner part of the bay, extending into the south-west zone. Since 1967, colonies of *Spartina anglica* began in the former saltings or on their frontal region, and among *Salicornia* populations. Nevertheless, the *Spartina anglica* area was still restricted (Figure 6B).

Since 1984, the spread of *Spartina anglica* has been rapid, the area occupied in 1988 was 4.9 ha (Figure 6C). The colonies of *Spartina anglica* near the racecourse (site 1, Figure 4) are from regrowth of fragments of the rhizomes remaining after scraping every year.

It is proposed that *Spartina anglica* will spread over the entire inner part of the bay (Figure 6D, sites D to F, Figure 4), the area on the west of the Chapel (site B, Figure 4), the south of the Kerallé River (site C, Figure 4), and the northern zone near the racecourse (sites I and J, Figure 4). Also, the submersion fre-

Table 1. *Cumulative mud accretion and rates of spread and estimated age of* Spartina anglica *from different locations in Kernic Bay.*

Location (see Figure 4)	Clone diameter (cm)	Size area (m^2)	Mud accretion (mm)	Estimated age	Concentric growth rate of clone (cm/year)
A	0	0	0	0 (1988)	
	30	0.07	—	1 year old	15
	60	0.28	—	2 years old	15
	100	0.78	—	3–4 years old	12.5–16.6
	174	2.38	—	5–6 years old	14.5–17.4
	240	4.54	50–100	8 years old	15
B	600	28.20	300	20 years old	15
D	335	8.76	100–120	11 years old	15.2
	325	8.29	slight	11 years old	14.8
E	525	21.64	180	17–18 years old	14.6–15.4
J	268	5.67	?	9 years old	14.8

Table 2. *Height of* Spartina anglica *stems from different locations in Kernic Bay.*

Location (see Figure 4)	Stem height (n = 30) mean +/− SE (0.05) (cm)			Local conditions
ISOLATED PATCHES				
A	38	+/−	4.3	protected zone, medium-grained sand
B	28	+/−	4.0	exposed zone, coarse sand
D	50	+/−	2.4	protected zone, mud over gravels
E	37	+/−	2.6	less protected zone, very fine sand
J	94	+/−	5.3	more protected zone, old vegetation, fresh water supply
SWARD VEGETATION				
C	52	+/−	3.8	silty beach near the Kerallé River
F	77	+/−	6.6	mud above gravels, fresh water supply
G	90	+/−	4.7	old vegetation
	69	+/−	5.1	sand near the river
	40	+/−	4.8	mud near the river
I	88	+/−	3.3	fine-grained sand

quency of the bay will decrease so that the monospecific sward will be progressively replaced by first *Puccinellia maritima*, and later *Halimione portulacoides*. The overgrown areas depending on the vertical tolerance of *Spartina anglica* will remain empty only in the central zone where channels and mobile sand occur, but the physical character of the shoreline will change with the noticeable decrease of the tidal volume.

PROJECTS OF COASTAL MANAGEMENT

Local authorities are trying to exclude or control the spread of *Spartina anglica* in order to maintain a large area in communication with the open sea for a windsurf project. Control of *Spartina anglica* in Irish estuaries (NAIRN, 1986; EVANS, 1986) has allowed the intertidal mudflats and sandflats to remain open to provide important foraging areas for grazing birds and other animals. The controlling methods included "clipping of seed heads, uprooting of whole plants and treatment with the herbicide Dalapon" (NAIRN, 1986). The first and third methods are arduous or hazardous and not very efficient. The removal of sediment to about 40 cm in Kernic Bay should eradicate most of the underground organs of *Spartina anglica* and prevent reinvasion. In a similar site, DOODY (1987) pointed out that "the impact of the creation of scrapes on the saltmarsh surface excavation of lagoons... are perhaps the most contentious issues in relation to management."

Sand removal in Kernic Bay offers many advantages because the sand is used in local agriculture. The substrate with *Spartina anglica* should be removed: (1) between the Kerallé River in the old saltmarsh; (2) north of and in the vicinity of the racecourse; and (3) south of the dirt road leading to the racecourse.

Sand removal should be undertaken near the old saltmarshes where *Spartina anglica* might spread.

An initial extraction of 40,000 m^3 was made in July 1989 (Figure 7), and notably lowered the ground-level in the north of the Kerallé River (sites F, H, and I, Figure 4). During the same operation, the area occupied by the *Spartina anglica* sward (about 2 ha) was significantly reduced. The effects of this local change on the physical and biological conditions in the Kernic Bay should be surveyed in the future.

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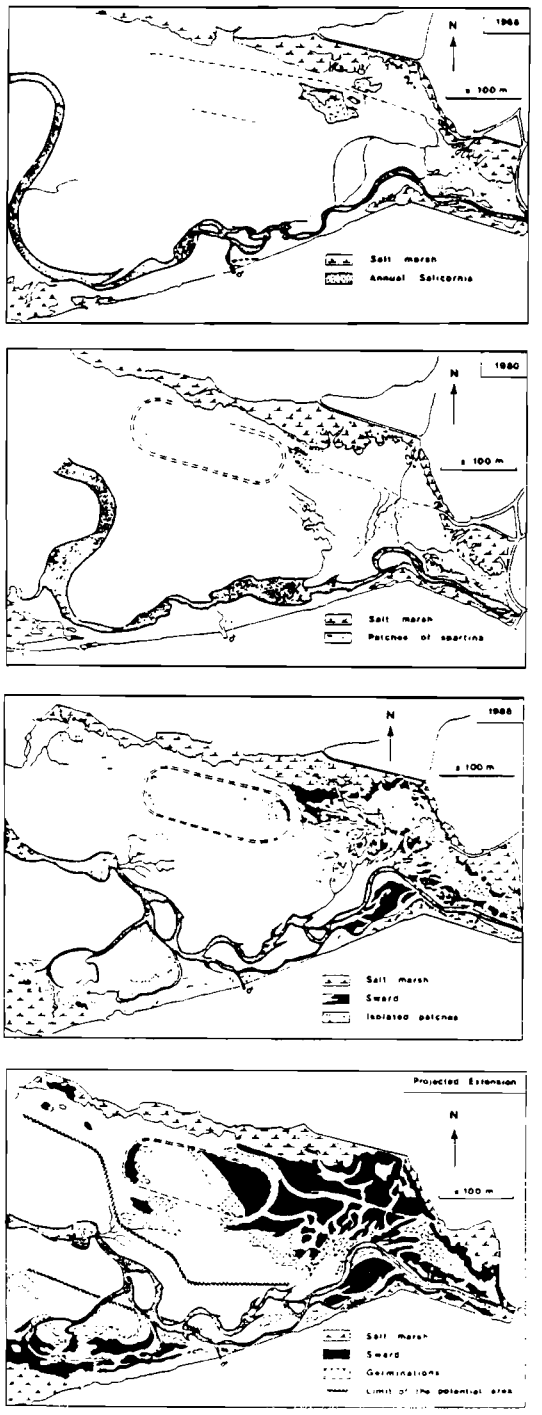

Figure 6. Chronological invasion of *Spartina anglica* in the Kernic Bay, followed by I.G.N. aerial photographs. (A) Top, 1966; (B) 1980; (C) 1988; (D) Bottom, Estimated extension of the *Spartina anglica* saltmarshes within a few years.

Figure 7. Drastic uprooting of *Spartina anglica* by sand extraction in July 1989.

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☐ ZUSAMMENFASSUNG ☐

Die Kernic-Bucht an der Nordküste ber Bretagne ist ein Küstenabschnitt mit großer touristischer und ökonomischer Bedeutung. Bislang hat ein jahreszeitlich auftretender Sedimentsabtrag die Verlandung der Bucht verhindert. Mit dem Ausbleiben dieser Erosionen und dem Auftreten von Schlickgras (spartina anglica) ergaben sich drastische Sedimentationen, die das Tidevolumen der Bucht verkleinerten. Dargestellt werden die sedimentologischen und hydrodynamischen Randbedingungen in der Bucht, die den derzeitigen Zustand verursacht haben. Von besonderer Bedeutung ist dabei der Einfluß des Schlickgrases in der inneren Bucht. Die Störungen der bisher beobachteten Prozesse sind in Zusammenhang mit der Einrichtung eines internationalen Windsurfer Zentrums zu sehen. Mehrere Methoden, das Schlickgras auszurotten, werden vorgeschlagen.

☐ RÉSUMÉ ☐

L'anse du Kernic, située sur la côte Nord de la Bretagne, est un site d'un grand intérêt touristique et économique. Jusqu'à une période récente, de régulières extractions de sable avaient limité le remplissage naturel de la baie par les sédiments. Depuis, de profondes modifications sont intervenues du fait de l'arrêt des extractions et de l'envahissement récent par une végétation à *Spartina anglica*, ayant conduit à un exhaussement des fonds et, consécutivement, à une réduction du volume tidal. Cette étude met en évidence les conditions sédimentologiques et hydrodynamiques du lieu, et analyse les étapes chronologiques qui ont abouti à l'état actuel, en particulier l'impact de l'envahissement par *Spartina anglica* des parties les plus internes de la baie. L'effet conjugué de ces processus est discuté au regard du projet des autorités locales de créer une base de vitesse pour planches à voiles. Plusieurs méthodes visant à supprimer la végétation à *Spartina anglica* sont ensuite exposées.

☐ RESUMEN ☐

La Bahía de Kernic, en la costa Norte de Bretaña, es una localidad de gran interés turístico y económico. Hasta un período reciente, las extracciones regulares de arenas han limitado el relleno natural de la bahía por los sedimentos. Más adelante, se han producido profundas modificaciones debido al hecho del cese de las extracciones y la invasión reciente por una vegetación de Spartina Anglica, que ha conducico a una elevación de los fondos y, consecuentemente, a una reducción del prisma de marea. Este artículo presenta las condiciones sedimentológicas e hidrodinámicas de la bahía de Kernic y la cronología de los sucesos que han conducido a la situación actual. Es de particular interés el impacto de la Spartina Anglica en las reas interiores de la bahía. Se analiza las interferencias entre estos procesos y el proyecto de las autoridades locales de desarrollo de una base internacional de windsurf en la bahía. Se propone varios métodos para la erradicación de la Spartina Anglica.—*Department of Water Sciences, University of Cantabria, Santander, Spain.*