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VARIATIONS OF SEAGRASS BEDS IN PONTEVEDRA (NORTH-WESTERN SPAIN): 1947-2001

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KEY WORDS: *Zostera noltii*, *Z. marina*, vegetation mapping, photo-interpretation, coastal vegetation

ABSTRACT

Despite their ecological importance the populations of seagrass beds are decreasing worldwide. That tendency has been documented in many coasts around the world, but there is a lack of quantitative studies from North-Western Spain. In our investigation we test if this decrease is taking place in the Atlantic Spanish coast and analyze their causes. Our results show a clear decrease in the populations of *Zostera noltii* Hornem. during the last 50 years in the Ria of Pontevedra, and that loss of the habitat and aggressive shellfishing techniques are the principal causes.

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INTRODUCTION

Seagrass beds are key elements of the coastal ecosystems in many parts of the world (see Hemminga & Duarte, 2000 for a complete review). Several studies stress their importance in different roles: they create highly structured habitats, which leads to a greater number of niches than in non-colonized areas, and as a result to a greater biodiversity (Currás *et al.,* 1993, Attrill *et al.*, 2000). From a geomorphologic point of view, they stabilize the coastline absorbing part of the wave energy, therefore reducing the erosion and facilitating the deposition of sediment and organic matter (Short & Neckles, 1999; Koch, 2001); furthermore, it has been documented an increase of coastal erosion where seagrass beds had been removed (Orth, 1976). They also pump nutrients from the water column and concentrate them into the sediment, making them available to the trophyc web (Touchette & Burkolder, 2000), regulate the oxygen concentration in the water column and increase the quality of the water by removing sediment and organic matter (Short & Neckles, 1999, Koch, 2001). Their high productivity is the base of an important trophyc web (Orth, 1976), rating about 1% of the marine primary production and more than 15% of the carbon fixed by the marine photosynthesis (Duarte, 1999). Seagrass beds gives shelter and food for the juveniles of many species of mollusks, crustaceans and fishes, many of them with a high economic value (Orth, 1976, Short & Neckles, 1999; Nagelkerken *et al.*, 2001).

Despite their importance, seagrass beds are reducing their populations worldwide, mainly as a consequence of human activities. Some well known examples are those in Chesapeake bay (Orth, 1976; Orth & Moore, 1983) or Galveston bay (Pulich & White, 1991). Besides the most obvious human interference destroying the habitats by fillings and construction on the coast-line, the main factor that causes the decline of seagrass populations is eutrophication, and its main effects are the increase of water turbidity and the seaweed blooms, both reducing drastically the availability of light for the seagrasses (Short *et al*., 2001). Some other human interventions are the direct damage by anchoring and boat propellers (Burdick & Short, 1999), or by shellfishing (Pasquelini et al,. 2000, Delgado *et al*., 1999, and our own observation).

In addition to these human impacts, some other episodes of great seagrass bed reduction due to natural causes have been recorded, like the 'wasting disease' that decimated the populations of *Zostera marina* L. in the Atlantic ocean in the 1930's (Vergeer et al., 1995).

Zostera noltii Hornem. is a small rhizomatous seagrass that occur mainly in the intertidal zones along the atlantic european coast, from Norway to Mauritania, but also in the Mediterranean and in the Black Sea (for instance Tutin, 1980, Phillippart, 1995, Auby & Labourg, 1996; Milchakova, 1999). In some areas of the Mediterranean and Denmark this species lives permanently submersed (Jacobs, 1982). In the coast of Galicia there is also *Zostera marina* L., a species very similar to *Z. noltii* of a bigger size. *Z marina* is distributed by the coasts of the Atlantic and Pacific oceans and in the Mediterranean, usually in permanent submersed situations (Kuo & Hartog, 2001).

Knowledge of the variation of the extension and distribution of seagrass beds is a necessary tool for the management of the coastal areas (Carruthres & Walker, 1999). There are many studies mapping the distribution of seagrasses all over the world, but in northwest Spain these maps are quite rare. The only references available of Galicia are the studies by Laborda et al,. (1997) on the distribution of *Zostera* in all the Spanish cantabro-atlantic coast in 1997, but with a very broad scale to be

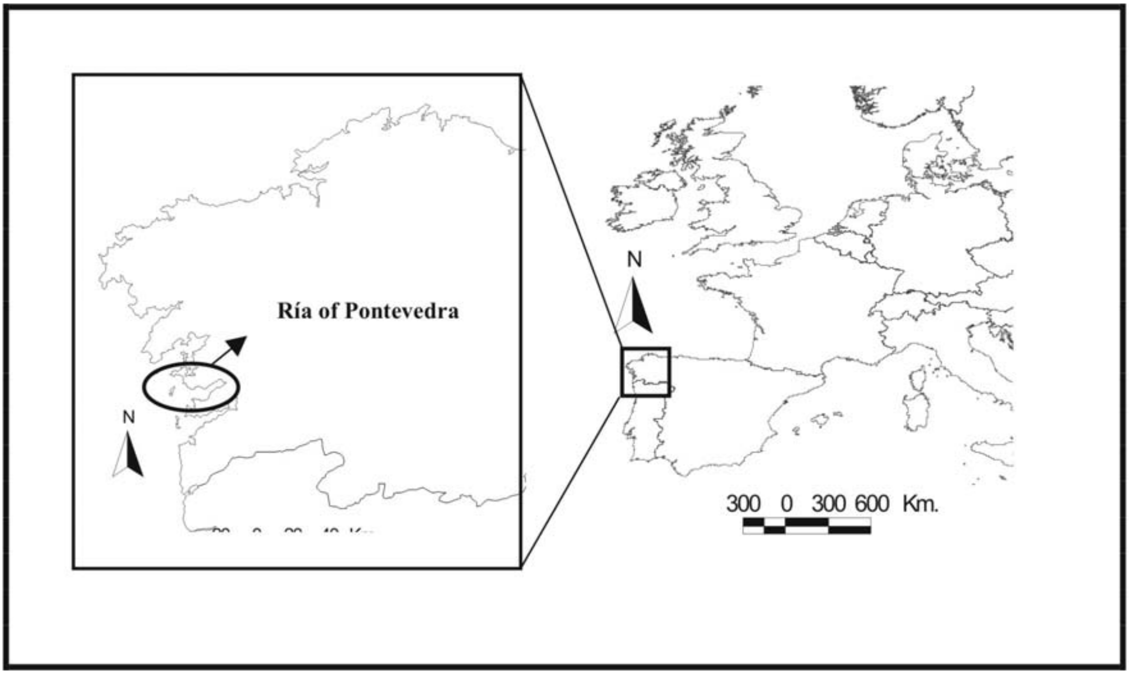

Figure1.
Situation of the study area.

locally useful; the vegetation maps of Izco & Sánchez, (1996 & 2002) of the Rias of Ortigueira and Betanzos are more accurate, but none of those studies analyze the distribution of *Zostera* in a historical context.

In this paper we map the current distribution of *Zostera* in the Ria of Pontevedra, and analyze the evolution of the *Zostera* beds during the last 50 years, along with the primary causes of that variation.

METHODS

The study area

The Ria of Pontevedra is located at the Atlantic coast of the north-western Iberian Peninsula (figure 1), with an estimated extension of about 145km^2 and a total length of 23 km; the main river in the area is the Lerez, with an estimated mean flow of 14.8 m^{3}s^{-1} (Fraga & Margalef, 1979).

Tidal regime is semi-diurnal, with a tidal amplitude ranging between 1 and 4 m at neap and spring tides respectively. Extensive intertidal plains are uncovered at low tide, being there where the seagrass beds develop. In these plains shellfishing of clams takes place, an activity of great economic importance in the area.

Climate in the area is temperate, with an annual mean about 14.2ºC, and a amplitude of 10.1ºC which describes the small differences between winter and summer. According to the Thornwhaite classification, climate in the area is "perhumid" and "mesothermic II", and according to Allue's, climate is characteristic of the Atlantic-European subregion, although quite close to the Mediterranean sub-humid with atlantic tendency (Carballeira et al,. 1983).

In the year 2000, temperatures of the sea surface (0-5m) in the Ria varied between a minimum of 12.4ºC in January and a maximum of 18.1ºC in September. (Centro de Control do Medio Mariño, Xunta de Galicia, personal communication).

In this paper we studied and mapped the distribution of *Zostera* at the inner part of the Ria of Pontevedra, between an imaginary line from the beach of Cantareira in the Poio municipality to the limit of the municipalities of Pontevedra and Marín at the west, and the bridge of A Barca in Pontevedra at the east (figure 2). The extension of this area at present is 781ha.

In order to analyze the different causes of the variation of the distribution of *Zostera*, we divided the area in four different sectors, where we considered that it could form continuous units since the habitat is not interrupted by any kind of barrier.

This sectors are the following (fig. 2):

Sector 1.- It's limits are the navigation channel in the north, the limit between the municipalities of Marín and Pontevedra at the west, and the contact between the navigation channel and the coastline at the east.

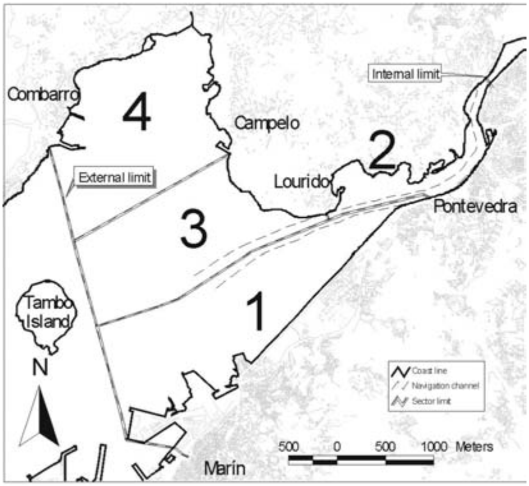

Figure 2.
The study area and the different sectors considered

Sector 2.- From Tres Hermanas at the southern shore, and the west part of the Polvorín beach at the northern shore, till Ponte da Barca at the east.

Sector 3.- Between the eastern part of the Polvorín beach and the dock of Campelo.

Sector 4.- Between Campelo and the new dock of Combarro.

The cartographic base was the digital map (scale 1:50.000) of the Galician Government (sheets 185-34, 185-35, 185-44, 185-54 and 185-55).

Aerial photographs were lent by the local office of the Spanish Coastal Service (Servicio Provincial de Costas de Pontevedra, Dirección General de Costas, Ministerio de Medio Ambiente). Of all the different photos available, we selected the pairs of the 1947 survey (black and white, scale 1:50.000), the first set available of this area, and those of the 2001 survey (color, scale 1:5000), the last available at the beginning of this study.

Photographs were scanned with a resolution of 600 ppp and orthorectified with the digital maps. The pixel size obtained was 2.31m from the 1947 photos, and

0.57m from the 2001 photos. All orthorectification, identification, and drawing of the *Zostera* polygons was done with the GIS ArcView 3.2TM (ESRI©), and the extensions CAD Reader, Image Warp and Xtools. In the orthorectification, a minimum of 14 points of control of the UTM projection were used for each photo. Since the distribution of *Zostera* is mainly two-dimensional, all the control points were selected at the coastline, at heights between zero and 5m. For each control point the root mean square error was calculated, and all those points with an error bigger than 10m were erased, and then the points with an error bigger than 2m were recalculated.

To calculate the area of potential habitat for *Zostera* that was lost, the coastline of the digital map was drawn with the photos of the years 1947 and 2001. The comparison of those two coastlines gave as a result a series of polygons that represent the loss of potential habitat for *Zostera* due to filling and coastline modifications in that period. We classified the different variations in one of the following four categories:

Sandbars (SB): the only sandbar in the area is in the inlet of Lourido. The form and size of this sandbar has been modified during the years, mainly by the alteration of the sedimentation pattern as a result of other coastline modifications in the area.

Urban construction (U): this category refers to the filling and subsequent construction of seaside walks, gardens or sporting fields. The main filling of this kind was done in the place known as A Seca, in the municipality of Poio.

Harbour constructions (H): fillings and construction of docks and port facilities. Some examples in the area are the docks of Estribela, Combarro and Campelo.

Roads and industrial constructions (RI): mainly the filling for the construction of the road "Avenida de Marín" and the ENCE-ELNOSA factory.

To determine the variation of the area occupied by the populations of *Zostera*, polygons were drawn on the orthorectified photos, with a magnification factor on the computer screen of 1:5000 for the 1947 photos and 1:1000 for the 2001 photos. The most suitable photos were used in each zone, discarding the marginal parts of each photo to avoid the lens distortion.

The patches of *Zostera* in the photo can be confused with dark spots of anoxic sediments, seaweed accumulations, deeper water zones or accumulation of mollusk and crustacean debris (McKenzie *et al*., 2001). To take this possibility into account, we considered three different classes according to plant density and the reliability of the image:

A. Patches of seagrass with high density (cover around 100%) in shallow waters, which makes this spots easily identifiable and reliable. Their boundaries are clear.

B. Spots with low density (cover under 50%), or susceptible of being confused as dark sediment. Spots in this category have a lighter color than the previous category, and their boundaries are diffuse.

C. Areas where the presence of *Zostera* is doubtful due to the possibility of confusion with seaweed, sediment or deep water. These spots tend to be the darkest.

Due to these problems with interpretation, the verification of the spots in the field is essential (Mckenzie *et al*., 2001, Orth & Moore, 1983). We verified the map of the distribution of *Zostera* obtained from the photos of 2001. This survey was conducted at low tide in the spring tides between October-December 2003. The map from the photos of 1947 suffered only minor corrections.

RESULTS

1. Habitat loss

The map resulting from the comparison of the coastlines in 1947 and 2001 is presented in the figure 3. It can be noticed a remarkable change in this period, mainly due to the fillings for port and industrial construction (table 1).

Table 1.
Modifications of the coastline in the period 1947-2001

Category	Number of modifications	Area (ha)
Sandbars	1	0.81
Urban	3	8.37
Harbour	4	38.56
Road and Industrial	5	57.94
TOTAL	**13**	**105.68**

Most of the coastline modifications in table 1 correspond with the category of roads and industrial constructions, and among them the most extensive is

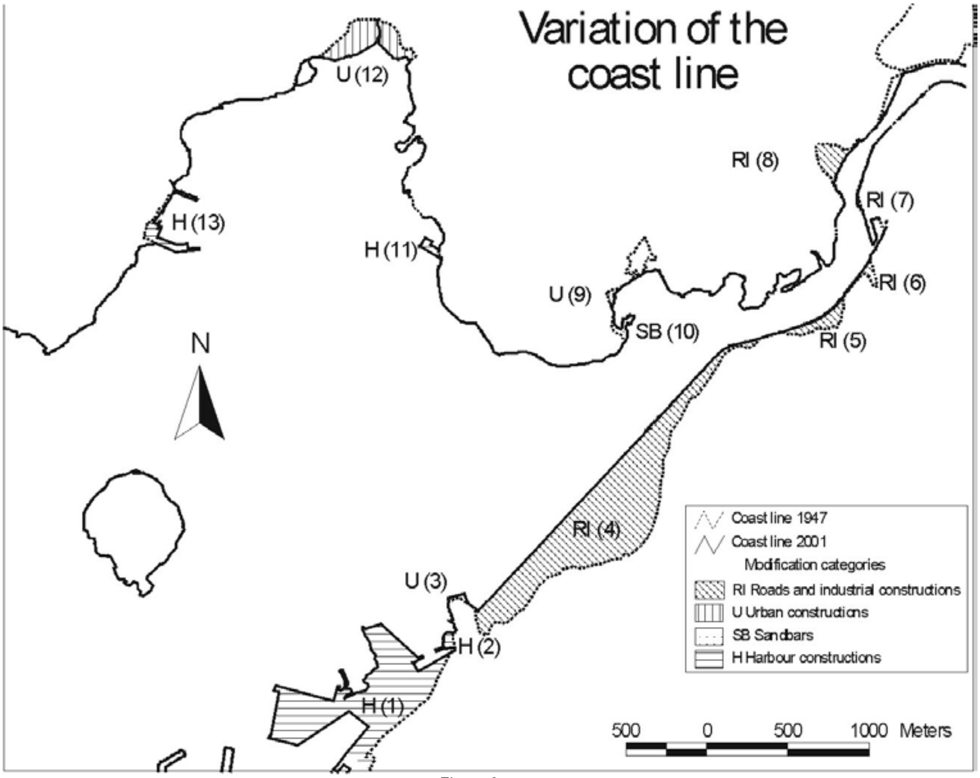

Figure 3.
Modification of the coast line during the period considered

the filling where the factory of ENCE-ELNOSA was constructed (51.7ha). The construction of docks and port facilities is the second cause of coastline modification, being the most remarkable the new docks of Marín, on a filling of 34.99ha. As can be easily noticed, most of the fillings were done in the southern shore of the Ría of Pontevedra (fig. 3).

In 1947 the total area of the study comprised 886.66ha, while in 2001 it had been reduced to 780.98ha; around 11.9% of the area was lost in that period. This figures includes some areas that probably could not be colonized by *Zostera*, as the main drainage channels or deep zones close to the three main harbours (H1, P2, H11 and H31 in figure 3), or some rocky areas (U3 in figure 3). Some other were colonized by salt marsh vegetation before the filling, and therefeore did not contain *Zostera* (e.g. E9).Considering this, the total loss of area susceptible to be colonized by *Zostera* can be estimated in 66.83ha.

2. Variation of the extension of *Zostera*

The populations of *Zostera* in the Ria de Pontevedra susceptible to be mapped from the aerial photos are composed mainly by *Z. nolti*i, although in some areas (mainly small intertidal pools) it is mixed with small patches or isolated individuals of *Z. marina*. In the intertidal zone we have not found any monospecific patch of *Z. marina* big enough to be mapped.

Based on the aerial photos of 1947, the total area occupied by *Zostera* was estimated in 247.36ha, 105.03 of them with a high plant density. The other 142.33ha were patches with low density or where the photo interpretation was doubtful (categories B and C, see methods) (figure 4). The area estimated from the photos of 2001 was 80.04ha, 55.18ha with high density (figure 5, table 2)

It can be easily noted that the number of patches increased in every class, while the mean surface per polygon decreased remarkably.

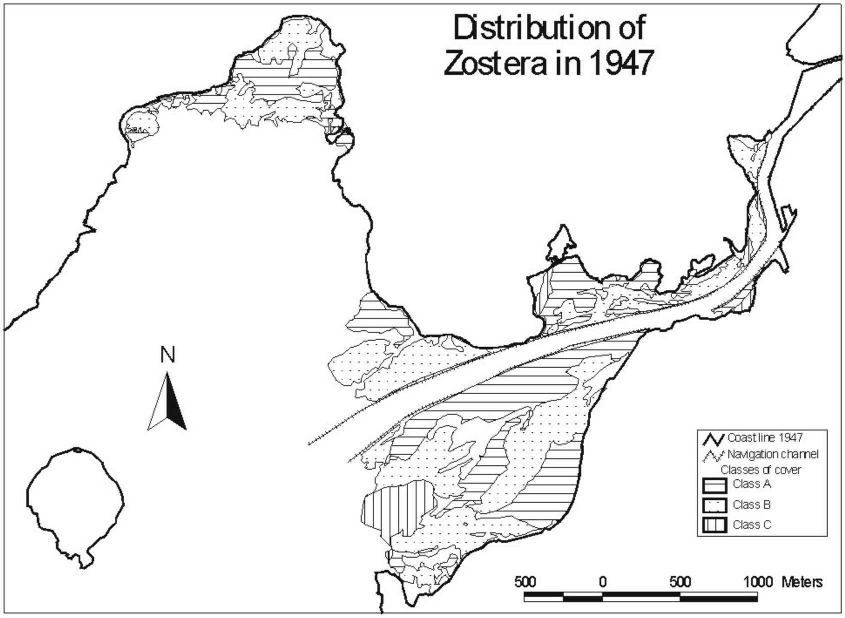

Figure 4.
Distribution of the seagrass in 1947

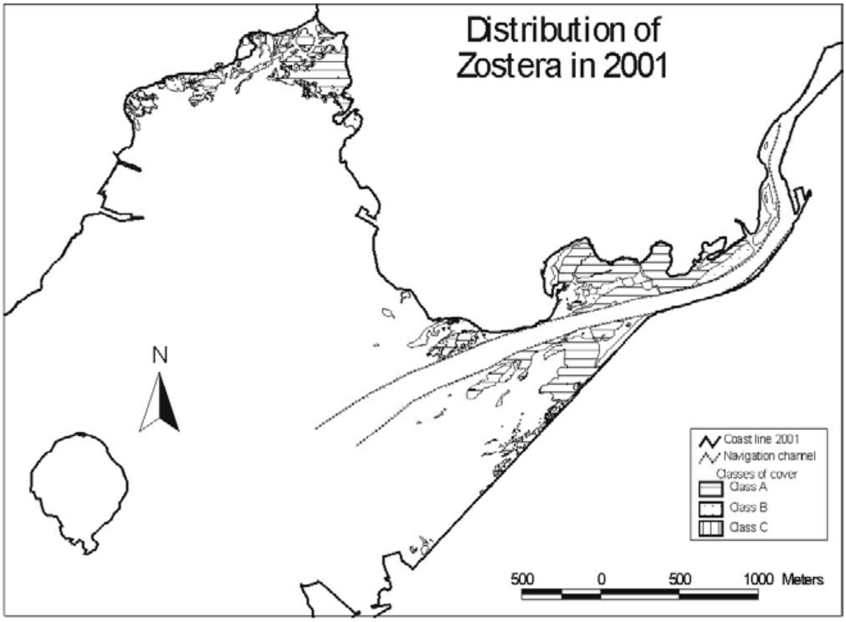

Figure 5.
Distribution of the seagrass in 2001

Tabe 2.
Cover of Zostera in each year and in every cover class

Year	Cover class	Number of polygons	Area (ha)	Polygon mean area (ha)
1947	A	20	105.03	5.25
	B	15	124.35	8.29
	C	8	17.98	2.25
	TOTAL	**43**	**247.98**	**5.75**
2001	A	185	55.18	0.30
	B	110	22.07	0.20
	C	24	2.80	0.12
	TOTAL	**319**	**80.04**	**0.25**

Now we'll analyze the evolution of the *Zostera* cover in each sector:

Sector 1 Most of the *Zostera* patches in 1947 were included in the A and B classes (62.09 and 58.53ha respectively). The total area occupied by *Zostera* in 1947 was 134ha, which was reduced to only 21.41ha in 2001, most of them of the class A. The total loss of area was therefore of 112.59ha, which accounts for about 84% of the 1947 area (fig. 6). Taking in account only the highest density class (A), the loss was about 70.83%.

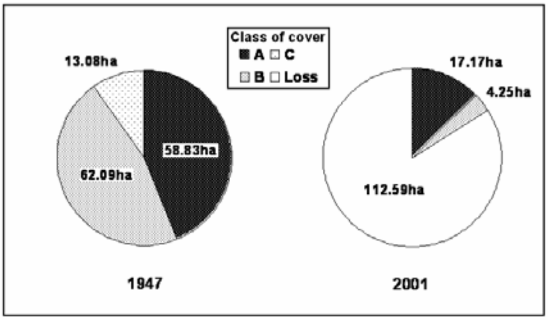

Figure 6.
Variation of the proportion of every cover class in sector 1 along the studied period

The total loss was maximum in this sector, which comprises all the filling for the construction of the ENCE-ELNOSA factory.

Sector 2. The reduction of the *Zostera* area was minimum in this sector, with a total loss of 10.68ha (26.7%). According to our estimation, the class with highest density (A) even increased its surface 3.2% (fig. 7).

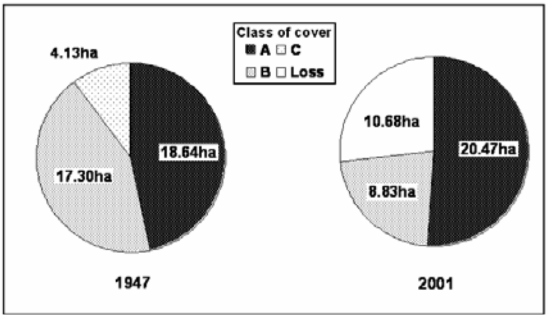

Figure 7.
Variation of the proportion of every cover class in sector 2 along the studied period

Sector 3. A total loss of about 28.22ha occurred during the studied period in this area (fig. 8). The more frequent class was the low-density (B), probably because the continuous impact of the shellfish gathering activities in this sector prevented a more dense colonization by *Zostera*. Moreover, the elimination of *Zostera* turned the sediment more

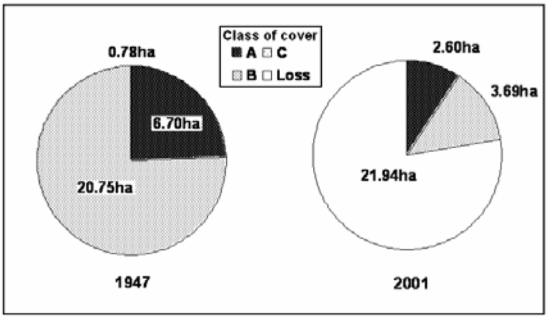

Figure 8.
Variation of the proportion of every cover class in sector 3 along the studied period

unstable, which made recolonization more difficult specially in exposed areas like this sector.

Sector 4. The *Zostera* loss in this sector was about 22.11ha. Most of the *Zostera* cover in 1947 was evenly distributed between the high and low-cover classes, while in 2001 the high-cover class (A) was the most frequent (fig. 9). Some new spots of the C class appeared in 2001, mainly in the areas were Zostera had a low-density in 1947 (fig. 9).

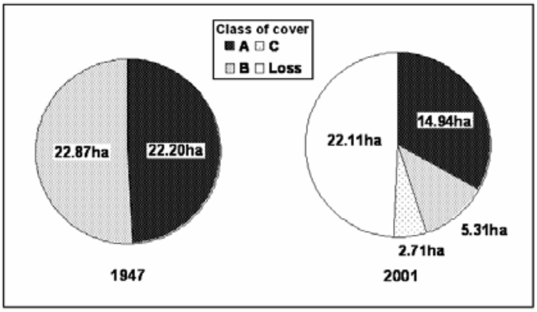

Figure 9.
Variation of the proportion of every cover class in sector 4 along the studied period

DISCUSSION

The destruction and loss of *Zostera* prairies has been recorded in several coastal areas around the world, sometimes with a natural cause as the 'wasting disease' in the 1930's (Vergeer *et al.,* 1995), but mostly as a consequence of human activities like eutrofization, mining, fishing and filling (Short *et al*., 2001 and references therein). The loss of seagrass beds implies the loss of all their functions and values, among them their contribution to the sustain of the fishing resources (Hemminga & Duarte, 2000; Short *et al.,* 2001).

Our data on the evolution of the area occupied by *Zostera* indicates a clear decrease of its total extension as well as an increase of the number of polygons, while the mean size of the polygon clearly decreases, which seems to correspond with a higher degree of fragmentation (table 2). Nonetheless we find necessary to have a brief look at the methodological limitation that can be conditioning our results to avoid some possible mistake that could misled the conclusions.

First, when interpreting aerial photographs there is always a source of error linked to the subjectivity of the interpretation. This error can be minimized by being the same person who interprets all pictures, and by doing a good field work to verify the result of the interpretation (McKenzie *et al*., 2001).

In this case there are two other possible sources of error in the photos themselves: first, the quality of the photographs used is not the same for both years. The photos of 2001 have more quality, color and a bigger scale (1:5000); the photos of 1947 are black & white and of a smaller scale (1:50000). Among other limitations, the different scale implies a more accurate drawing from the 2001 photos, that can bring a false impression of a greater fragmentation (and smaller mean size of the polygons) in that year. Those differences advice to be cautious when considering vegetation changes at a large scale (Lathrop *et al.,* 2001). On the other hand, some of the polygons of 2001 could be corrected with the field work in 2003 (actually adjusting the distribution of *Zostera* to its present state), but that correction could not be done for the 1947 photos. This asymmetry in the approach could explain the greater frequency of the low-density classes (B and C) in the 1947 map.

A possible third problem, i.e. the time of the year when the photographs were taken, could be obviated because, although biomass in the prairies of *Zostera* changes along the year (Vermaat *et al*., 1987; Pérez-Lloréns & Niell, 1993; Veermat *et al,*. 1993; Philippart, 1995; Veermat & Verhagen, 1996; Auby & Labourg, 1996; Laugier *et al.,* 1999), density in this area is not very variable along the year (Cochón, unpublished data). Some other small-scale problems, like the dying out in the most elevated zones due to the summer drought (Peralta *et al*., 2002 and personal observation) were either too small to be taken into account or corrected during the field survey.

Our raw data showed a loss of the *Zostera* area of about 167.32ha between 1947 and 2001 (67.64%). Considering the possibility of committing some of the errors mentioned, and taking in account that this errors affect most to the low-density or doubtful classes (B and C), the actual loss of *Zostera* must be somewhere between these figures and those of the most reliable class (A), which suffered a loss of about 47.47% of its original area in 1947.

In any case, our data clearly showed a significant loss of the extension of seagrass in the Ria de Pontevedra, mainly due to the fillings. Fillings in this period occupied an area of 105.48ha, burying about 52.19ha where *Zostera* lived in 1947, 20ha of them of high-cover (class A). Most of the losses were in sector 1 (42.66ha, 18.36 of the high-density class A), mainly due to the filling for the construction of the ENCE-ELNOSA industrial complex (RI4 in figure 3). Therefore, this filling only accounts for a 17.24% of the total surface in 1947 (17.48% of the high-density areas). The second remarkable impact on the *Zostera* populations was that of the "A Seca", in the municipality of Poio (U12 in figure 3), which corresponded to a filling used to build sports facilities. About 5ha of *Zostera* were buried by this filling, most of them with high density (class A).

The second cause of the decrease of *Zostera* in this area was an increase of the shellfish culture and gathering activities. The impact of these activities was quite conspicuous in the studied area, as mentioned by Laborda et al. (1997). Shellfishing in this area is mainly on clams, so the substrate of *Zostera* is usually affected by two different actions, each with a different kind of impact on the populations of *Zostera*: the sowing of shellfish juveniles is done with the aid of tractor and plough, resulting in the alteration of extensive areas at a time (figure 10). This can be considered the most severe impact related to this activity. On the other hand, the gathering is done mainly on foot, with a hoe to overturn the sediment. This action causes two different kind of effects, the most obvious is the digging of many small holes in areas with *Zostera*, and a second effect is the trampling of the plants, specially near the accesses to the intertidal plain, where all the fishers must pass.

Figure 10.
Damage on the seagrass bed after the sowing of clam juveniles

These impacts can be worsened in some exposed areas where the tidal currents are stronger (Fonseca *et al.,* 2002), or in the highest spots of the intertidal plain, where plant growing is limited by long periods of emergence, specially in summer (Peralta *et al*., 2002). The decrease of density that these activities cause can also result in a lower growing rates due to the decreasing of the mutuality (sensu Hanson, 1962), and therefore a decreasing of the resilience of the *Zostera* populations.

The importance of shellfishing in the Galician 'Rías Baixas', and among them in the Ria of Pontevedra, was relatively small until the 1940's. Until that time it was a secondary activity in the area, practiced for self-consume or for the local markets. Only oyster fishing had a large-scale commercialization (FAMRV 1984). It is from the 1950's when shellfishing experienced a complete change, mainly due to the economic development of the area, which produced an easier commercialization as well as the development of a strong canning industry (Agrafojo, 1991). From then on, some fishing methods extremely aggressive for the sea bottom were used, as the 'cleansing' of the *Zostera* prairies (the complete elimination of the plants to simplify shellfishing activities) (FAMRV, 1984). Therefore, we can assume that the pressure on the *Zostera* population increased significantly after the year 1947.

In this work we found a significant decrease in the area of the seagrasses *Zostera noltii* and *Zostera marina* in the Ria of Pontevedra during the period studied. This decrease is related to local rather than global causes, and to direct human actions (filling and shellfishing) rather than to water contamination.

To stop or reverse this tendency in this area, in our opinion two main factors must be dealt with: first, a strict limitation of the fillings and seaside constructions. Second, a work remains to be done to explain to the fishermen the benefits of seagrass beds, as a necessary step to change some of the aggressive actions and techniques related with shellfishing.

Acknowledgements.

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