Manuscript Number:

Title: What are the costs and benefits of biodiversity recovery in a highly polluted estuary?

Article Type: Research Paper

Keywords: biodiversity valuation; water treatment investment; recovery of aquatic systems; Nervión Estuary; Basque Country.

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Abstract: There is an important lack of focus on biodiversity restoration measures when dealing with the restoration of degraded aquatic systems. Furthermore, the application of biological valuation methods has been applied only spatially in previous studies, and not both, in a temporal and spatial scale. The intense monitoring efforts carried out in a highly polluted estuary, in northern Spain (Nervión estuary), allowed for the valuation of, both economically and biologically, the costs and benefits associated with a 21 years sewerage scheme application. It can be concluded that the total amount of money invested into the sewage scheme has contributed to the estuary´s improvement of both abiotic and biotic factors, as well as increasing the uses and services provided by the estuary. However, different direct or time-lagged responses were observed at the inner and outer parts of the estuary. Understanding the costs and know-hows of the environmental recovery of degraded aquatic systems helps policy makers and regulators to formulate robust, cost-efficient and feasible management decisions.

Highlights:

- Biodiversity restoration valuation as a measure of the recovery of a polluted estuary

- We established cost-benefit links between restoration investment, abiotic and biotic recovery

- The cost-benefit analysis of the abatement actions can assist decision-makers with management

What are the costs and benefits of biodiversity recovery in a highly polluted estuary?

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Abstract:

There is an important lack of focus on biodiversity restoration measures when dealing with the restoration of degraded aquatic systems. Furthermore, the application of biological valuation methods has been applied only spatially in previous studies, and not both, in a temporal and spatial scale. The intense monitoring efforts carried out in a highly polluted estuary, in northern Spain (Nervión estuary), allowed for the valuation of, both economically and biologically, the costs and benefits associated with a 21 years sewerage scheme application. It can be concluded that the total amount of money invested into the sewage scheme has contributed to the estuary´s improvement of both abiotic and biotic factors, as well as increasing the uses and services provided by the estuary. However, different direct or time-lagged responses were observed at the inner and outer parts of the estuary. Understanding the costs and know-hows of the environmental recovery of degraded aquatic systems helps policy makers and regulators to formulate robust, cost-efficient and feasible management decisions.

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1. Introduction

Due to increasing habitat degradation (Halpern *et al.*, 2008), there is an increasing need to restore degraded ecosystems (Lotze, 2010). Hence, legislation worldwide, such as the Clean Water Act, in the USA, or the Water Framework Directive (WFD; 2000/60/EC) and the Marine Strategy Framework Directive (MSFD), in Europe, includes restoration of degraded aquatic habitats as one of their primary goals (Apitz *et al*., 2006; Borja *et al*., 2008a, 2010).

From an economic perspective, estuaries offer a wide range of economically quantifiable goods and services to society, such as productive biological resources, and other non-commercial ones, such as intrinsic biological diversity and its protection and filtration functions (America, 2008). Thus, their ecological restoration may be a worthwhile investment for society as it can lead to improvements or enhancements in the supply and quality of ecosystem services to society (Aronson *et al*., 2010).

However, most contributions use the recovery of the ecosystems structure and functioning or the recovery of a specific biological ecosystem component / species as indicators of restoration (Borja *et al*., 2006b; Elliott *et al*. 2007; Gorostiaga *et al*., 2004; Mialet *et al*., 2010; Whitfield & Elliott, 2002) rather than societal benefits. Likewise, no studies have looked at total biodiversity recovery when dealing with restoration.

Many methods have recently been developed which value biodiversity directly (Balvanera *et al.*, 2006; Beaumont *et al.*, 2007; Derous *et al.*, 2007; Nijkamp *et al.*, 2008; Pascual *et al.*, submitted) or indirectly (using contingent valuation; choice experiments; etc.).

Despite this, most measures of biodiversity valuation look at the spatial biodiversity and none of the studies have approached its valuation on a spatial and temporal scale.

Furthermore, there are very few examples of long-term monitoring data sets, that include different biological and physico-chemical data from both water and sediments, which would be useful for showing the recovery trajectories after remediation or restoration processes (Borja *et al*., 2010).

One of these examples occurs at the Nervión estuary (northern Spain), where the intense monitoring system carried out for many years, gives the opportunity for observing the development of the ecosystem as water quality improves; providing a valuable record of the status of the different ecosystem components.

The estuary of the Nervión was one of the most polluted areas on the northern coast of Spain (Cearreta *et al*., 2004; Borja *et al*., 2006a). This estuary, which harbours one of the most important ports in Spain, has suffered from serious environmental degradation as a result of many pollutant discharges (both industrial and domestic), since the 19th Century, together with the development of the iron, steel and shipbuilding industries and mining activities (Cearreta *et al*., 2004). This industrialisation led to a sharp increase in population, with the consequent intensification of domestic untreated wastewater inputs into the estuary (García-Barcina *et al*., 2006).

Furthermore, the original morphology of the estuary was strongly modified, with the consequent loss of wetlands and sand dunes. Nowadays only 68% of its original extension remains, due to the channelling and straightening of its course, the diking of large intertidal areas, intense dredging activities to maintain navigation in the channel, etc. (Fernández Pérez, 2005). Hence, the Nervión estuary represents a good example of man induced alteration and is regarded as a heavily modified water body, according to the European WFD (Borja *et al.*, 2009).

However, in 1979 the Sewage Scheme for the area was approved by the competent local water management authority (*Consorcio de Aguas Bilbao-Bizkaia* (CABB)), establishing as the overall objective the restoration of good aesthetic and sanitary conditions along the estuary, and fixing a water quality standard of 60% dissolved oxygen saturation; the environmental clean-up of the catchment waters began in 1990 which included physical and chemical treatments; the biological treatment began in 2001 (García-Barcina *et al.*, 2006). The latter describes the sewage treatment scheme, which includes more than 200 km of sewer network, where the waters of more than one million inhabitants convey into a central Waste Water Treatment Plant (WWTP), with a biological treatment capacity of 6 m^3 s^{-1} (Figure 1).

As a consequence of this sewage scheme start-up, a change in the condition of the Nervión estuary from an 'open-navigable-sewer' to an aerobic tideway, supporting many ecosystem components, has occurred over the last 21years (García-Barcina *et al.*, 2006).

The water quality improvement of the Nervión estuary has been described by many authors (Borja *et al.*, 2006b, 2010; García-Barcina *et al.*, 2006, González-Oreja & Sáiz-Salinas, 1999) throughout the different phases of the water treatment. At least, a total investment of around €600 million was made, including support from national, Basque, and provincial governments, as well as through higher water service user charges (Barreiro & Aguirre, 2005). However, up until now, the real costs and benefits of the sewage scheme still remain unknown, both in terms of economic input quantification and biological valuation.

Hence, the aims of this study are: (i) to value, both biologically and economically, the costs and benefits associated with the sewage scheme over the last 21 years, and the subsequent ecological recovery that has taken place in the waters of the estuary of Nervión, and (ii) to highlight the benefits of using these biological and economic techniques as instruments to formulate the robust, cost-efficient and feasible water treatment decisions as required by policy makers and regulators.

2. Materials and Methods

2.1. Study area

The Nervión estuary is located on the northern coast of Spain (Figure 1) and drains a watershed of about 1,700 km^2, which provides an annual average freshwater inflow of 25 m^3 s^{-1}. The estuary has two areas: a narrow, relatively shallow and highly stratified channel of about 15 km in length, that crosses the metropolitan area of the city of Bilbao (hereafter, 'inner part') and a semi-enclosed coastal embayment, with an area of about 30 km^2 and an average water depth of about 25 m (hereafter, 'outer part') (Figure 1).

Extensive monitoring of the area has taken place since 1989 (Franco *et al*., 2010), within the framework of regional projects. A synthesis of the methods used and the ecosystem components sampled (which included zooplankton, macroalgae, macrobenthos and fishes) are given in Franco *et al*. (2010), Borja *et al*. (2006b; 2010) and Díez *et al*. (2009).

2.2. Databases

Economic, abiotic and biological temporal trends were analysed from 1989 to 2010. All the public and private economic environmental expenditure information, publicly available in the annual economic reports of local businesses and environmental incentive investments announced in the official bulletins of the regional area, were gathered into an economic input database.

A filtering was applied in order to gather only the information for the sewage scheme actions from 1985 to 2010 and, following Pollution Abatement Costs and Expenditures (PACE) 2005 survey guidelines (U.S. Census Bureau, 2008), expenditure actions were divided into four types of activities: treatment / capture, disposal, recycling, and pollution prevention. The criteria for this subdivision are presented in Table 1.

Although certain expenditures may have multiple benefits, for the purposes of this survey, only those for treatment / capture, for which pollution abatement is the primary purpose, were considered. When pollution abatement capital expenditures include any installation or equipment for the treatment / capture activities, only incremental capital expenditures and incremental operating costs additional to annual operating investments or maintenance costs were taken into account (following U.S. Census Bureau, 2008). These expenditures were budgeted and adjusted, where possible, as a time-frame cost according to the estimation of the average life of the equipment. By doing so, we avoided referring to capital expenditures as one-off costs, which could also lead to an overestimation of the investment efforts being made at the beginning of each installation commissioning.

In order to determine the aggregate economic effort being put into abatement, GDP deflator values (per year) (World Bank) were applied to all investments.

As a proxy for the water treatment results, the temporal trends in annual load of biochemical oxygen demand (BOD) and nutrient load discharges, evaluated as ammonia (NH_3), were studied. The BOD was computed from the main sources: domestic, industrial, WWTP effluent and river pollution. These data were obtained from García-Barcina *et al.* (2006) and were updated using CABB unpublished data.

The biological information of the ecosystem components, for which detailed spatial distribution data were available (zooplankton, macroalgae, macrobenthos and demersal fish), were included and integrated in a database, in order to obtain a Biological Valuation Map (BVM) of the Nervión estuary for each of the 21 years that the sampling period lasted. The zooplankton relative abundance database covered a total of 16 sampling years (1994-2009) (Villate *et al.*, 2004; Aravena *et al.*, 2009). The three year macroalgae sampling period database, with percentages of spatial cover, was only available for the hard-bottom substrata (Díez *et al.*, 2009).

The macrobenthos was intensively sampled and studied during the period 1989-2010 for the soft-bottom substrata (Borja *et al.*, 2006b, 2010) and only for three years of the sampling period for hard-bottom substrata (Pagola-Carte and Sáiz-Salinas, 2001). The soft-bottom database consisted of a set of sample sites where abundances (per sampled surface area) were known, while the hard-bottom database samples only provided presence / absence data. Fish abundance data, from 1989 to 2010, were obtained from trawling capture surveys (Uriarte and Borja, 2009). Trawl data covering multiple grid cells were treated so that every grid cell visited by the trawl was given the abundance value of the entire trawl.

Although there has been an important increase in the use of the Nervión estuary by seabirds (Soler *et al*., 2008; Borja *et al.*, 2010), due to the lack of seabird point spatial data, the changes in this ecosystem component were excluded.

Finally, general data quality control was undertaken (geographical coordinates, dates, time, and taxonomy). The taxonomy was checked against ERMS (European Register of Marine Species), in order to avoid the use of synonymous taxa that could overestimate the number of species (Pascual *et al*., submitted).

2.3. Methodology

The Biological Value (BV) of the four ecosystem components was analysed according to the Biological Valuation Methodology developed for the Belgian part of the North Sea, by Derous *et al*. (2007). The same methodology has already been applied by Pascual *et al*. (submitted) to the entire Basque continental shelf. This methodology allows for a better valuation of the overall improvement of the ecosystem biological components identified in the Nervión estuary. Due to the inherent differences of the two parts of the estuary (inner and outer), regarding the pollutant discharges and human pressures, the changes of the BV in both areas were assessed independently. In fact, these differences in human pressures were the reasons for dividing the estuary into two water bodies (inner and outer), for the implementation of the WFD (Borja *et al.,* 2006a). The minimum width of the inner part of the estuary is 50 m, thus, it was decided to divide the whole study area into 25 x 25 m grid cells for the valuation of the ecosystem components.

The aim of the BV methodology is to provide an integrated view on nature's intrinsic non-anthropogenic value of the subzones (relative to each other) within a study area (Derous, 2007). By interrogating a set of assessment questions (Table 2a), within the database, through mathematical algorithms, it is possible to visualize all the biodiversity aspects linked to the biological and ecological valuation. These questions were determined in a European workshop, after expert judgement, and focus their criteria on rarity and aggregation-fitness consequences (Derous *et al*., 2007).

As this methodology aimed to determine the costs and benefits of restoration, Elliott *et al*. (2007) and Simenstad *et al*. (2006) ask the necessary question 'what are we restoring to?'. In this case, a literature review was used to determine the different criteria for each assessment question and ecosystem component. A summary of the application criteria is shown in Table 2b.

Table 2a questions five and six address the occurrence and quantity of Habitat-Forming (HF) or Ecologically Significant (ES) species. The selection of the species in each of these categories was the result of both a large scale and detailed literature review and local expert judgement on each ecosystem component.

Where possible, this analysis is as objective as possible although subjectivity cannot always be excluded in this BV method and, therefore, this selection should be regarded as expert judgment assessment choices (Derous *et al*., 2007). A detailed classification of the selected species, per ecosystem component, for each category and the criteria followed is shown in Table 3.

Due to the lack of subzone specific data, quantitative scoring is often not possible and the subzones are weighted qualitatively, scored against each other, or semi-quantitatively, ranking subzones in categories of high, medium or low value (Derous *et al.*, 2007). In this study, each of the ecosystem components was valued separately by averaging the scores of the used assessment questions, giving each assessment question an equal weight over the total score. The integrated BV of each of the subzones was then determined by averaging the values obtained for the different ecosystem components (when values were available). Five biological value classes were used in the proposed scoring system (very low, low, medium, high and very high) as this allowed for a better detection of value patterns without losing too much detail (Pascual *et al.*, submitted).

In order to avoid possible bias, which could occur when the amount of information for each subzone was not equal (Breeze, 2004), 'reliability' and 'sampling effort' labels were attached to each of the BV for a better interpretation of the results. Reliability and sampling effort labels display the quality and amount of data (respectively) used to assess the BV.

The results of the BV of the study area per year were then presented on various maps (Figure 2) which integrate all of the available biological information for the different ecosystem components; each subzone was assigned a colour corresponding to its value. Reliability and sampling effort values, together with the BV per year, are displayed in Table 4.

In order to determine the significance of the relationships between variables, correlation analyses were performed using Statgraphics Plus 5.0 (Statsoft, Inc. 2000).

2.4. Interpolation

The BV for each of the ecosystem components cannot be calculated for all cells of the

Nervión estuary, but only at those locations sampled. However, values can then be interpolated to give estimates at sites where no samples are available using GIS-aided inter- and extrapolation methods, as interpolation gives values in such points where no measurements are available, by converting point data to surface data. This approach allows the creation of a full-coverage BV for each of the ecosystem components for the whole Nervión estuary (Pascual *et al*., submitted).

3. Results

The economic data (Figure 3a) show that, almost €658 million have been spent to date on the sewage scheme on actions directed towards the improvement of the quality of the estuary conditions (99% of it came from CABB and 1% from private businesses). Investments over €30 million were applied for the years 1989, 1990, 1993, 1997, 1998 and 2000, which coincides with the years of major treatment and capture equipment acquisition (tanks, waste water treatment facilities, etc.).

The abiotic data (Figure 3b) show that the BOD of the industrial and domestic waste water inputs into the estuary has decreased since 1990, with a noticeable decrease in the BOD input by the WWTP from 2001 onwards. Uncontrolled BOD river pollution loads continued to fluctuate between these years. Ammonia loads also show an overall decreasing trend from 1990 onwards.

The BV of both inner and outer parts of the Nervión estuary (Figure 3c) shows some fluctuations throughout the CABB sewage scheme period (1989-2010) (Table 4). Decreases in the inner part occurred for the 1992-1993, 1999-2000 and 2001-2002 periods, while decreases in the outer part are observed for the 1989-1990 and 2001-2002 periods.

However, in general, a clear improvement in the BV, from low (2.00) to almost very high (4.77), is observed for the inner part of the Nervión estuary. This improvement is also noticeable, to a lesser extent, for the same period, for the outer part of the Nervión estuary where BV increases from almost medium (2.83) to high (4.46) values.

This improvement in BV is clearly seen in Figure 2, together with the BV clearly increasing upstream along the estuary with time.

The performance of the reliability and sampling effort values along the sewage scheme period (Table 4), in general show that both inner and outer areas increased from having lower reliability values towards medium reliabilities, with some higher reliability values obtained during specific years. Both of the decreased reliabilities obtained for 2010 were due to having obtained the latest data for only two of the four ecosystem components (soft substratum macrobenthos and demersal fish). Sampling effort remained constant in the inner part of the Nervión estuary, whilst these efforts increased from medium to high at the outer part of the estuary.

When comparing these improvements in the total ecosystem component BV with the cumulative money invested in abatement actions (€), BOD and NH_3 annual loads into the estuary, there is a clear increase in the BV upgrade together with a cumulative increase in the total abatement action investments and the decrease in the BOD and NH_3 into the estuary (Figure 3).

There are significant direct or time-lagged responses correlations between BOD / Cumulative Investment / NH_3 with the changes to the BV of the inner and outer parts (Table 5a); the results of the correlation analysis between the inner BV and the outer BV are shown in Table 5b.

There is a highly significant negative correlation, between the cumulative amount of money invested and the loads of BOD and NH_3 into the estuary (Table 5a), i.e. an increase of funding reduced the inputs; while the correlation between BOD and NH_3 is also significant but positive, i.e. the higher BOD and NH_3 loadings occurred in the same years.

In addition, there is a significant positive correlation between the cumulative investments and the inner part BV, showing an increasing ecological response to the investments, although the same relationship is non-significant for the outer part of the estuary (Table 5a).

The correlation between the BOD and NH_3 and the BV at the inner part of the estuary is significant but negative and it increases along with the increase in the time lags (Table 5a). However, only a significant negative correlation between BOD and outer BV evolution is observed when applying a time lag of 6 years between them and no significant relationships are observed between NH_3 and outer BV.

There is a significant positive correlation between the BV of the inner and outer areas (Table 5b).

The overall summary of the significance of the relationships between the variables is shown in Figure 4.

4. Discussion

Knowing the total amount of money invested during the 21 year period of the sewage scheme, allows us to obtain the cost values of the pollution abatement actions (Figure 3a). However, although care was taken when gathering the economic investment data, the total of the abatement costs should also be treated with caution. The difficulties when accessing the separation of businesses economic data allowed us identifying particular types of capital expenditures and operating costs related only to pollution abatement, for some of the businesses, but not for others.

In addition, by referring to some of the capital expenditures as one-off costs could also lead to an overestimate of the investment effort being made at the beginning of all installation commissioning. However, an incorrect splitting of capital expenditure by the estimation of the average life of installations, could underestimate the investment being applied to the sewage scheme.

As stated above, public users have also paid an environmental tax in order to fund the clean-up programme (35% of the total sewage scheme funding is thought to come from customers). While this payment is involuntary, however, we suggest using these customers' payment boundaries as baseline values of society's Willingness to Pay (WTP), for the environmental improvement of the Nervión estuary, as it reflects the actual value given by society for a change in the water resource under the pollution contingency.

Both BOD and NH_3 loads show a direct negative correlation with the cumulative investment. García-Barcina *et al*. (2006) support this finding as they reported that water quality showed statistically significant increases in dissolved oxygen saturation and decreases in ammonia nitrogen, which can primarily be attributed to the pollution abatement measures undertaken by the local water authority.

The overall BV improvement (Table 4 and Figures 2 & 3c) shows a clear biological improvement in the Nervión estuary (see also Borja *et al.*, 2010). This improvement is more apparent in the inner part of the estuary especially as this area suffered the worst environmental conditions, such as notable oxygen depletion, loss of fauna and flora species, and aesthetic problems (Saiz-Salinas and González-Oreja, 2000). The improved oxygen level in the water also supported the increased penetration upstream of species which are sensitive to pollutants, allowing for the improvement of the BV at this inner part (Borja *et al.*, 2006b; Leorri *et al.*, 2008).

It is notable that the inner and outer parts of the estuary react differently to the financial investments and abiotic improvements. While there is a direct increase response in the BV in the inner part, together with the increase in cumulative investment and the decrease in the BOD and NH_3 loads, the BV at the outer part only seems to respond to the direct increase in the inner BV and the decrease in the BOD within a time lag of six years.

This allows us to further corroborate the fact that pressures, and therefore responses, differ between the inner and outer parts of the Nervión estuary and that, as stated in Borja *et al*. (2006a), these should be regarded as two different water bodies with different management approaches and different times of recovery.

Despite this, there is a strong response of the BV to specific management actions (Figure 3c). As such, in 1990, as a consequence of the commissioning of Galindo WWTP, the data shows an immediate increase in the BV in the outer part of the estuary, as well as a 2 year time-lag response in the inner part of the estuary.

This one unit increase in the BV of the outer part is followed by a BV decrease in 1992 probably due to the start of the external port dock works, that has persisted to the present, and which involved dredging and working activities that led to the re-suspension of polluted sediments.

The increasing treatment and capture of the waste water discharges by the WWTP reduced pollutant loads to the Nervión estuary (García-Barcina *et al.*, 2006). This allowed for the respective increase and stabilization of the BV in the inner and outer parts.

The further closure in 1996 of one of the main iron and steel industries, Altos Hornos de Vizcaya (AHV), allowed for a further BV improvement observed both in the inner and outer parts (Borja *et al.,* 2006b, 2008b, 2010).

The implementation of the biological treatment at the Galindo WWTP (in 2001), which provides organic matter and nitrogen removal, greatly reduced the contribution of the plant effluent (see Figure 3b) to the overall load (García-Barcina *et al*., 2006). As a result, a primary decrease was observed in the BV of both areas subsequent to the treatment start-up and a posterior increase and stabilization of the BV in the inner and outer parts, respectively.

The decrease in the BV in the outer part of the Nervión estuary coincided with the periods of major port and dock building works at the Abra of Bilbao (Phases I & II) (1991-1993) and with major dredging in the area (2001), which could be responsible for this decrease of almost half a unit in the BV, as detected in the benthic component (Borja *et al.,* 2009).

The application of the BVM allows us to collate all observed improvements into a single value whose evolution can be studied throughout the whole sewage scheme period. This approach has previously been used by other authors (Derous *et al.,* 2007; Forero, 2007; Rego, 2007; Vanden Eede, 2007; Weslawski *et al.,* 2009; Pascual *et al*., submitted) although most have concentrated on the spatial biodiversity and have not approached its valuation in a joint spatial and temporal scale. The Nervión estuary provides the opportunity for observing the response of the ecosystem to investment and as water quality improves, providing a valuable record of the status of the different ecosystem components throughout time.

There are many other examples of estuarine condition improvements due to sewage abatement actions worldwide (Aslan-Yilmaz *et al*., 2004; Brosnan and O´Shea, 1996; Conley and Josefson, 2001; Hawkins *et al*., 2002) including the notable example from the Thames estuary (Andrews, 1984; and Attrill, 1998). However, until now there has been no comparison between investment and biodiversity valuation.

As Boesch (2002) states, the high variability in environmental conditions together with the existence of time lags in recovery responses make the evaluation of progress in achieving goals in pollution reduction a challenge. But having time lags between responses also allows us to determine the resilience times or the “habitat restoration / recovery times” of an ecosystem (Drechsler and Hartig, 2011).

Comparing the recovery times obtained by Andrews (1984), for the Thames estuary, with the ones for the Nervión estuary, similar time spans of 10 to 11 years are obtained, which coincides with the recovery time boundaries stated in Borja *et al*. (2010), for most of the aquatic ecosystem components. Following the earlier model in Elliott *et al* (2007), Borja *et al* (2010) have partly quantified a conceptual model of changes to the state of the Nervión estuary, where the different states, to which the estuary can evolve, according to a total or incomplete resilience, are discussed. Therefore, knowing the resilience time of both inner and outer parts of the estuary allows us to determine which of the recovery states the system is in and, thus, help to formulate robust, cost-efficient and feasible water treatment decisions as is required from regulators and policy makers.

As stated above, estuaries offer a wide range of economically quantifiable goods and services to society (America, 2008). Together with the estuary’s improvement, new uses and services have developed in the Nervión estuary: European bathing water quality standards were met at local beaches (García-Barcina *et al.*, 2006) and different recreational activities started occurring on and around the estuary (rowing competitions, recreational fishing competitions, canoeing, boat-cruises, etc.). However, this study was unable to analyse the further link between the environmental improvement of the estuary and the increase on its services provision. However, the authors highlight this as a possible area for further study in the Nervión estuary. Figure 4 summarizes the overall findings of our study and allows us to conclude that the total amount of money invested into the sewage scheme of the Nervión estuary has contributed to the improvement of: firstly, the abiotic factors and secondly, the biotic factors.

However, there is still the potential for further improvements in the BV of the estuary (especially at the outer part). Forthcoming sewage scheme activities announced by the CABB will enable these further improvements; these include the building of a sewage sludge incinerator, another WWTP, a possible submarine outfall (to avoid the development of harmful algae blooms within the inner estuary (Fernández-Pérez, 2005), and the total renewal of the pipelines.

Furthermore, the better control and limiting of dredging activities and diffuse and riverine pollution (i.e. through the building of storm tanks (Fernández-Pérez, 2005)), would further reduce the loads of uncontrolled inputs into the estuary, allowing for its continued recovery.

5. Conclusions

Our approach successfully combined the ecological and economic data allowing us to fulfil the cost / benefit analysis of the Nervión estuary sewage scheme plan.

Pollution abatement actions carried out in the Nervión estuary, which reduced the BOD and total NH_3 waste input values, resulted in a significant increase in the BV for the inner and outer parts of the estuary.

However, the BV at the outer part showed a time lag of six years between performing the actual actions and its response.

Furthermore, variations in BV, along the sewage scheme, respond to the different human impacts and actions that have occurred along the Nervión estuary and the findings are complicated by interactions between different management measures at different places.

An increase in the uses and services provided by the estuary is observed together with its environmental and ecological recovery.

The successful clean-up of the Nervión estuary shows that it is possible to redeem even an extremely polluted aquatic ecosystem, acting as an example for decision makers on how and by how much the recovery of a highly polluted estuary is possible.

6. Acknowledgements

Data for this study were obtained from different projects funded by the Consorcio de Aguas Bilbao-Bizkaia. M. Pascual was supported by a grant from the *Technological Centres Foundation* of the Basque Country. We wish to thank the Institute of Estuarine and Coastal Studies and the University of Hull, UK, for receiving M. Pascual in an internship stay. Ainhize Uriarte (AZTI-Tecnalia) kindly provided us with fish data. The Department of Applied Economy, at the University of the Basque Country, is also thanked for kindly advising us on some details of this contribution. This is paper number XXX from the Marine Research Division (AZTI-Tecnalia).

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Table 1. Division criteria table for the total sewage scheme abatement actions applied at the Nervión estuary (Modified from U.S. Census Bureau, 2008)

	Activity Category	***Examples***
Pollution Abatement Capital Expenditures	Treatment / Capture	Purchase, installation and start-up costs of "end of pipe" pollution abatement equipment: - Absorption and filtering systems. - Emissions capture systems. - Oil/water separating systems. - Dewatering systems. - Loads control and capture systems. - Decontamination systems. - Treatment and purification systems. - Pollutant substances elimination processes and systems. - Pouring-off systems. - Distillation columns; compactors, etc.
	Recycling	- Reuse, recovery and recirculation systems. - Water consumption reducing systems. - Recycling equipment. - Recycling facilities installations.
	Disposal	Construction of waste storage facilities or retention ponds
	Pollution Prevention	- Set-up; fit-up and renewal actuations. - Sewage management decisions. - Pollution prevention; disposal; efficiency; environmental impact and measures to emplace reporting. - Environmental appointment establishment (ISO 14001 and others).

Table 2:

a) Set of assessment questions, related to the different structure and processes of biodiversity (Derous *et al*., *2007*)
(†) When only abundance /presence / covertures data was available
(‡) When only mean density values data was available, as occurring with the macrobenthos_hard ecosystem component data

b) Set of assessment questions criteria for each of the ecosystem components assessed
* Rarity and Commonness defined as those <0.05% of the total number of individuals and as those >0.5% of total number of individuals, respectively (Gering *et al*., 2003)
[1] According to Borja & Collins, 2004 (Table 18.1)
[2] According to AMBI´s defined Ecological Groups I-V
[3] According to Borja *et al*., 2004
[4] According to Wells et al., 2007 (Table 3)
[5] According to Uriarte & Borja, 2009

a)

Question Code	***Assessment Questions (Following Derous et al., 2007)***
Q1	Is the subzone characterized by | High counts / presence / covertures of many species?† The mean density values? ‡
Q2	Is the abundance / relative abundance / coverture / presence of a common* species very high in the subzone? Is the subzone characterized by mean biodiversity values?
Q3	Is the subzone characterized by the presence of many rare species?
Q4	Is the abundance / relative abundance / coverture of rare species high in the subzone?
Q5	Is the abundance / relative abundance / coverture of habitat forming species high in the subzone?
Q6	Is the abundance / relative abundance / coverture of ecologically significant species high in the subzone?
Q7	Is the species richness in the subzone high?

b)

Ecosystem Component	***Data availability***	***Q1***	***Q2***	***Q3***	***Q4***	***Q5***	***Q6***	***Q7***
Zooplankton	1994-2009	† (count)	Relative abund.	Rarity*	Relative abund.	-----------	≥ 80% of Relative abund.	nº sp.
MB_Soft	1989-2010	‡ [1]	Mean biodiv[1]	Rarity*	Abund.	Abund.	≥ 50% of abund.[2]	nº sp. [1]
MB_Hard	2004/2006/2008	† (pres.)	Presence	Rarity*	-----------	Au or All	C; H; DF;FF	nº sp.
Macroalgae_Hard	2003/2004/2006	† (cov.)	Coverture	Rarity*	Cov.	≥ 75% of Cov.	% of Cov.[4]	nº sp. [3]
Dem. Fish	1989-2010	-----------	-----------	Rarity*	Abund.	-----------	% [5]	% [5]

Table 3: List of selected a) Habitat-Forming (HF) and b) Ecologically-Significant (ES) species for each of the ecosystem components.
Key: 5 = Very High Biological Value; 4 = High Biological Value; Au = Autogenic; All = Allogenic; C = Carnivores; H = Herbivores; FF = Filter feeders; DF = Deposit feeders.[1]According to Uriarte & Villate, 2004; [2]According to Pascual *et al.*, (submitted); [3]According to AMBI´s defined Ecological Groups I-V; [4]According to Wells et al., 2007 (Table 3); [5]According to Uriarte & Borja, 2009.

a) Habitat- Forming (HF) Species

Zooplankton	**MB_Soft**[2]	**MB_Hard**[2]		**Macroalgae_Hard**[2]	**Dem. Fish**
----------------	Abra alba (5)	Anomia ephippium (Au)	Mytilaster solidus (All)	Bifurcaria bifurcata (5)	-----------
	Abra nitida (4)	Balanus amphitrite (All)	Mytilus galloprovincialis (Au)	Corallina elongata (5)	
	Abra prismatica (5)	Balanus crenatus (All)	Ostrea edulis (All)	Corallina officinalis (5)	
	Abra sp. (4)	Balanus perforatus (All)	Ostreidae (Au)	Cystoseira baccata (5)	
	Cerastoderma edule (4)	Balanus sp. (Au)	Pollicipes pollicipes (All)	Cystoseira tamariscifolia (5)	
	Scrobicularia plana (5)	Balanus trigonus (All)	Sabellaria spinulosa (All)	Gelidium corneum (5)	
	Tellina tenuis (5)	Chthamalus sp. (Au)	Sabellidae (Au)	Gelidium spinosum (5)	
	Venus sp. (5)	Chthamalus stellatus(Au)	Spongia caudigera (Au)	Halopteris filicina (5)	
		Mytilaster minimus (All)	Verruca stroemia (Au)	Lichina pygmaea (5)	
				Lithophyllum byssoides (5)	
				Mesophyllum lichenoides (5)	
				Stypocaulon scoparium (5)	
				Verrucaria maura (5)	

b) Ecologically- Significant (ES) Species

Zooplankton[1]	**MB_Soft**[3]	**MB_Hard**[2]		**Macroalgae_Hard**[4]	**Dem. Fish**[5]
Phyllum Cnidaria (5)	Ecological Group I (5)	Actinia equina (C)	Jassa marmorata (FF)	Phyllum Chlorophyta (1)	Omnivorous (5)
Phyllum Rotifera (1)	Ecological Group II (4)	Amphiglena mediterranea (FF)	Lasaea adansoni (FF)	Phyllum Rodophyta (5)	Piscivorous (5)
Class Gastropoda (5)	Ecological Group III (3)	Apherusa jurinei (FF)	Melarhaphe neritoides (DF)		Flat fish (5)
Class Maxillopoda (5)	Ecological Group IV (2)	Aplysia punctata (H)	Modiolula phaseolina (H)		
Class Polychaeta (1)	Ecological Group V (1)	Bittium reticulatum (H)	Modiolus barbatus (H)		
Order Tintinnida (5)		Campecopea hirsuta (H)	Musculus costulatus (H)		
Genus Acartia (5)		Caprella danilevskii (H)	Paracentrotus lividus (H)		
		Caprella penaltis (C)	Patella depressa (H)		
		Cymodoce truncata (DF)	Patella rustica (H)		
		Dynamene bidentata (H)	Patella ulyssiponensis (H)		
		Eulalia viridis (C)	Patella vulgata (H)		
		Gastrochaena dubia (FF)	Platynereis dumerilii (H)		
		Hyale perieri (H)	Polydora sp. (DF)		
		Hyale spinidactyla (H)	Syllis amica (C)		
		Hyale stebbingi (H)	Syllis gracilis (C)		
		Ischyromene lacazei (H)	Tanais dulongii (FF)		
		Jassa falcata (FF)			

Table 4. A summary of the total Nervión estuary Biological Values, Reliability and Sampling effort; mean values and standard deviations, per year are shown.

	Outer			Inner		
Year	**BV**	**Reliability**	**Sampling effort**	**BV**	**Reliability**	**Sampling effort**
1989	2.83 ± 0.75	3.00 ± 0.00	1.67 ± 0.82	2.00 ± 0.00	1.00 ± 0.00	3.00 ± 0.00
1990	3.56 ± 0.82	1.10 ± 0.45	2.55 ± 0.83	1.97 ± 0.16	1.05 ± 0.32	3.00 ± 0.00
1991	4.65 ± 0.56	1.10 ± 0.45	2.98 ± 0.13	2.00 ± 1.01	1.03 ± 0.23	2.03 ± 1.01
1992	4.41 ± 0.64	1.20 ± 0.60	2.93 ± 0.31	2.95 ± 0.31	1.12 ± 0.46	3.00 ± 0.00
1993	3.93 ± 1.24	1.05 ± 0.22	2.49 ± 0.50	2.01 ± 0.11	1.03 ± 0.23	3.00 ± 0.00
1994	4.34 ± 0.55	2.12 ± 0.92	2.38 ± 0.68	3.29 ± 1.18	2.35 ± 0.81	2.79 ± 0.41
1995	4.40 ± 0.62	2.53 ± 0.50	2.95 ± 0.22	3.64 ± 0.84	2.35 ± 0.81	2.57 ± 0.82
1996	4.02 ± 1.03	1.58 ± 0.55	2.97 ± 0.22	3.43 ± 1.42	2.01 ± 0.11	2.44 ± 0.82
1997	4.42 ± 0.59	2.53 ± 0.50	2.97 ± 0.16	3.42 ± 1.55	2.56 ± 0.50	2.77 ± 0.45
1998	3.94 ± 0.75	2.07 ± 1.00	2.94 ± 0.27	4.09 ± 1.04	1.70 ± 0.69	2.98 ± 0.21
1999	4.42 ± 0.59	2.07 ± 1.00	2.70 ± 0.46	4.49 ± 0.69	2.44 ± 0.90	2.98 ± 0.19
2000	4.62 ± 0.89	2.98 ± 0.12	2.86 ± 0.43	3.65 ± 1.07	2.13 ± 0.99	2.79 ± 0.41
2001	4.82 ± 0.62	2.55 ± 0.50	3.00 ± 0.00	4.43 ± 0.84	2.13 ± 0.99	2.79 ± 0.41
2002	4.15 ± 0.62	2.01 ± 0.97	2.72 ± 0.47	3.43 ± 1.16	2.02 ± 1.00	2.74 ± 0.68
2003	4.06 ± 1.33	2.10 ± 0.99	2.45 ± 0.88	3.51 ± 0.77	2.00 ± 0.98	2.55 ± 0.70
2004	3.76 ± 1.01	1.77 ± 0.94	2.26 ± 0.70	4.02 ± 0.89	1.16 ± 0.54	2.70 ± 0.54
2005	4.11 ± 1.05	2.23 ± 0.98	2.41 ± 0.76	3.76 ± 0.54	2.08 ± 1.00	2.93 ± 0.34
2006	4.37 ± 0.91	2.15 ± 0.98	2.71 ± 0.68	4.22 ± 1.24	2.01 ± 0.98	2.79 ± 0.43
2007	3.83 ± 0.79	2.13 ± 0.99	2.79 ± 0.57	4.00 ± 0.64	2.03 ± 1.00	2.85 ± 0.38
2008	4.36 ± 0.94	2.18 ± 0.98	2.72 ± 0.50	4.49 ± 0.66	2.04 ± 1.00	2.84 ± 0.42
2009	4.32 ± 0.71	2.11 ± 1.00	2.90 ± 0.40	4.78 ± 0.58	2.04 ± 1.00	2.84 ± 0.42
2010	4.46 ± 0.50	1.02 ± 0.13	3.00 ± 0.00	4.77 ± 0.42	1.00 ± 0.00	3.00 ± 0.00

Table 5. a) Correlation analysis results between the BV of both inner and outer parts of the estuary with the total annual loads of Biochemical oxygen demand (BOD); with the total cumulative economic investments and with the total annual loads of ammonia nitrogen (NH_3). b) Correlation analysis results between the BV of inner and outer parts. Numbered suffixes determine the time lag applied (ex. BV_inner_1= the Biological value at the inner part at a time lag of 1 year).

Significant correlations are highlighted in bold and leveled *α=0.05; **α=0.01 or *** α=0.001

(Key: η = number of samples; r= correlation coefficient; p-value= probability value)

a)

	BOD			**Cum. Investment**			**NH3**		
	η	r	p-value	η	r	p-value	η	r	p-value
BOD				**18**	**-0.9726**	**_0.0000***_**	**18**	**0.9385**	**_0.0000***_**
Cum. Invest.	18	0.0820	0.7464				18	-0.9107	**_0.0000***_**
BV_inner	18	-0.6646	**_0.0026**_**	18	0.7342	**_0.0005***_**	18	-0.5087	**_0.0311*_**
BV_outer	18	0.1279	0.6130	18	-0.0730	0.7734	18	0.1621	0.5205
BOD_1				17	-0.9638	**_0.0000***_**	17	0.8990	**_0.0000***_**
Cum. Invest_1	18	0.2556	0.3059				17	-0.9161	**_0.0000***_**
BV_inner_1	18	-0.7645	**_0.0002***_**	17	0.7675	**_0.0003***_**	17	-0.5386	**_0.0257*_**
BV_outer_1	18	-0.2908	0.2418	17	0.0561	0.8305	17	-0.0944	0.7186
BOD_2				16	-0.9533	**_0.0000***_**	16	0.8967	**_0.0000***_**
Cum. Invest_2	18	-0.1464	0.5620				16	-0.9270	**_0.0000***_**
BV_inner_2	17	-0.7418	**_0.0007***_**	16	0.7633	**_0.0006***_**	16	-0.5375	**_0.0318*_**
BV_outer_2	17	-0.2954	0.2497	16	0.0340	0.9005	16	-0.0295	0.9135
BOD_3				15	-0.9411	**_0.0000***_**	15	0.8851	**_0.0000***_**
Cum. Invest_3	17	-0.1968	0.4491				15	-0.9332	**_0.0000***_**
BV_inner_3	16	-0.8335	**_0.0001***_**	15	0.8038	**_0.0003***_**	15	-0.6380	**_0.0105*_**
BV_outer_3	16	-0.3447	0.1911	15	0.0728	0.7966	15	-0.0973	0.7300
BOD_4				14	-0.9119	**_0.0000***_**	14	0.8752	**_0.0000***_**
Cum. Invest_4	16	-0.2902	0.2757				14	-0.9406	**_0.0000***_**
BV_inner_4	15	-0.7670	**_0.0008***_**	14	0.7988	**_0.0006***_**	14	-0.6482	**_0.0122*_**
BV_outer_4	15	-0.3867	0.1545	14	0.2393	0.4100	14	-0.1405	0.6320
BOD_5				13	-0.8994	**_0.0000***_**	13	0.8688	**_0.0001***_**
Cum. Invest_5	15	-0.3834	0.1583				13	-0.9312	**_0.0000***_**
BV_inner_5	14	-0.8288	**_0.0002***_**	13	0.8462	**_0.0003***_**	13	-0.7663	**_0.0022**_**
BV_outer_5	14	-0.5161	0.0589	13	0.3352	0.2628	13	-0.2977	0.3232
BOD_6				12	-0.9364	**_0.0000***_**	12	0.9144	**_0.0000***_**
Cum. Invest_6	14	-0.2959	0.3043				12	-0.9079	**_0.0000***_**
BV_inner_6	13	-0.8442	**_0.0003***_**	12	0.9120	**_0.0000***_**	12	-0.8774	**_0.0002***_**
BV_outer_6	13	-0.5574	**_0.0478*_**	12	0.4500	0.1421	12	-0.3426	0.2757
BOD_7				11	-0.9284	**_0.0000***_**	11	0.9103	**_0.0001***_**
Cum. Invest_7	13	-0.4346	0.1378				11	-0.8879	**_0.0003***_**
BV_inner_7	12	-0.8682	**_0.0002***_**	11	0.8532	**_0.0008***_**	11	-0.8449	**_0.0011**_**
BV_outer_7	12	-0.5566	0.0602	11	0.3272	0.3260	11	-0.2001	0.0552
BOD_8				10	-0.9132	**_0.0002***_**	10	0.8623	**_0.0013**_**
Cum. Invest_8	12	-0.2421	0.4483				10	-0.8655	**_0.0012**_**
BV_inner_8	11	-0.9301	**_0.0000***_**	10	0.9102	**_0.0003***_**	10	-0.8673	**_0.0012**_**
BV_outer_8	11	-0.4163	0.2029	10	0.2107	0.5589	10	-0.0805	0.8250

b)

	BV_outer			**BV_outer_1**			**BV_outer_2**		
	η	r	p-value	η	r	p-value	η	r	p-value
BV_inner	22	0.4563	***0.0328****	22	0.4087	0.0589	21	0.2884	0.2048
BV_inner_1	21	0.1264	0.5850	21	0.4356	***0.0484****	21	0.4080	0.0718
BV_inner_2	20	0.0789	0.7408	20	0.0766	0.7482	20	0.4332	0.0564

Figure 1

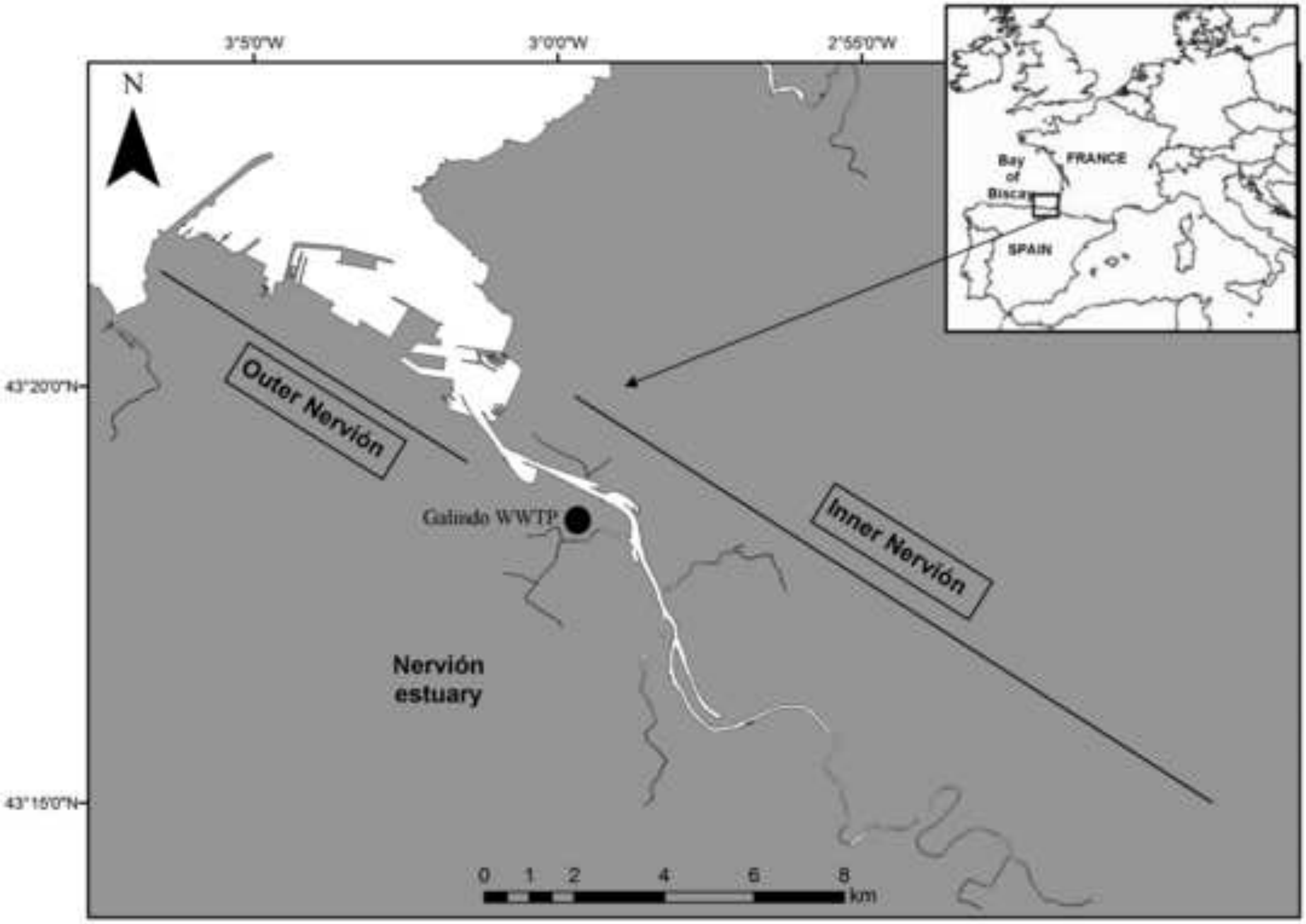

3°5'0"W
3°0'0"W
2°55'0"W
43°20'0"N
43°15'0"N
N
Outer Nervión
Inner Nervión
Galindo WWTP
Nervión estuary
0
1
2
4
6
8
km
Bay of Biscay
FRANCE
SPAIN

Figure 2 Black and White

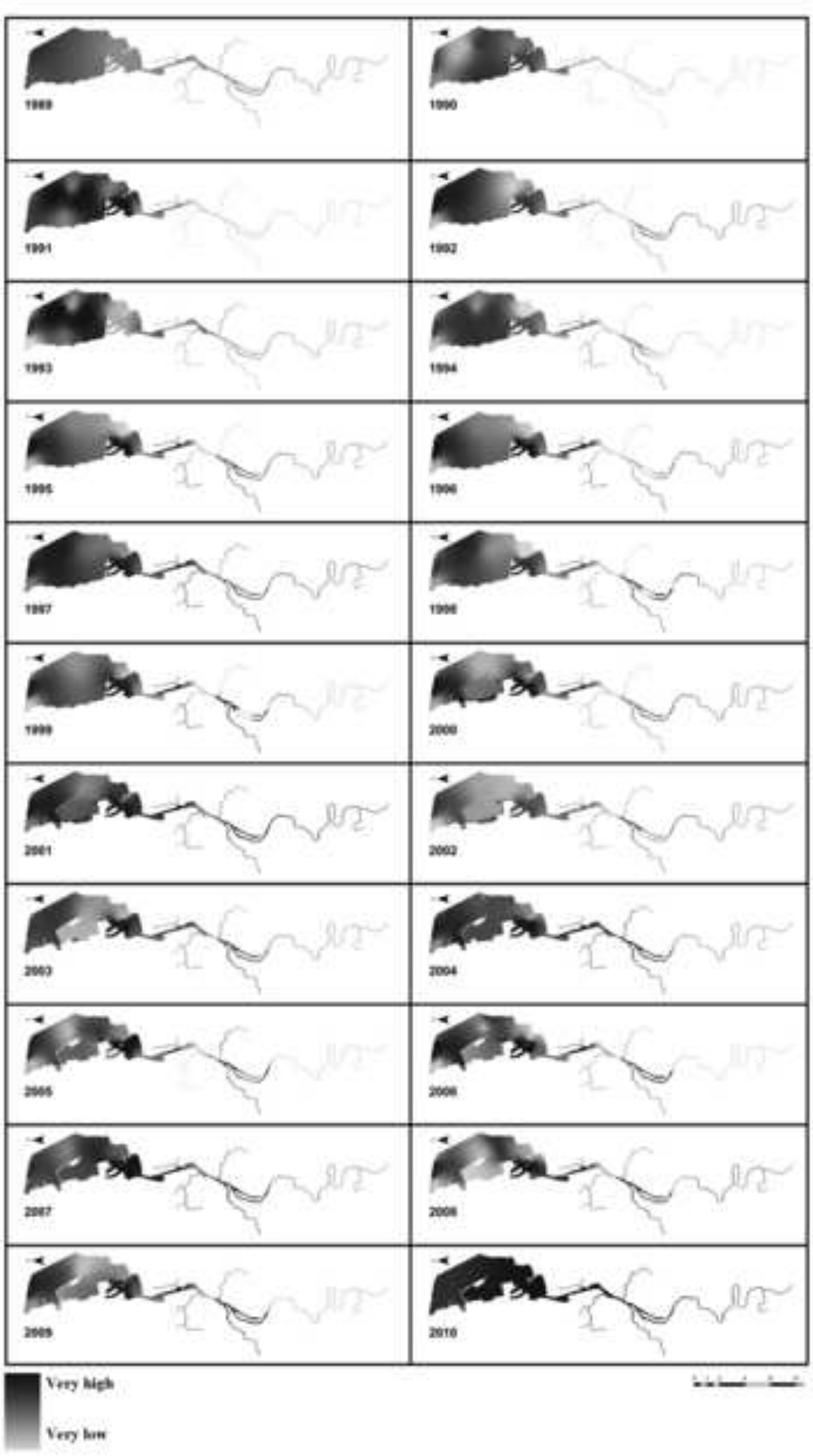


Figure 2 Color_web only

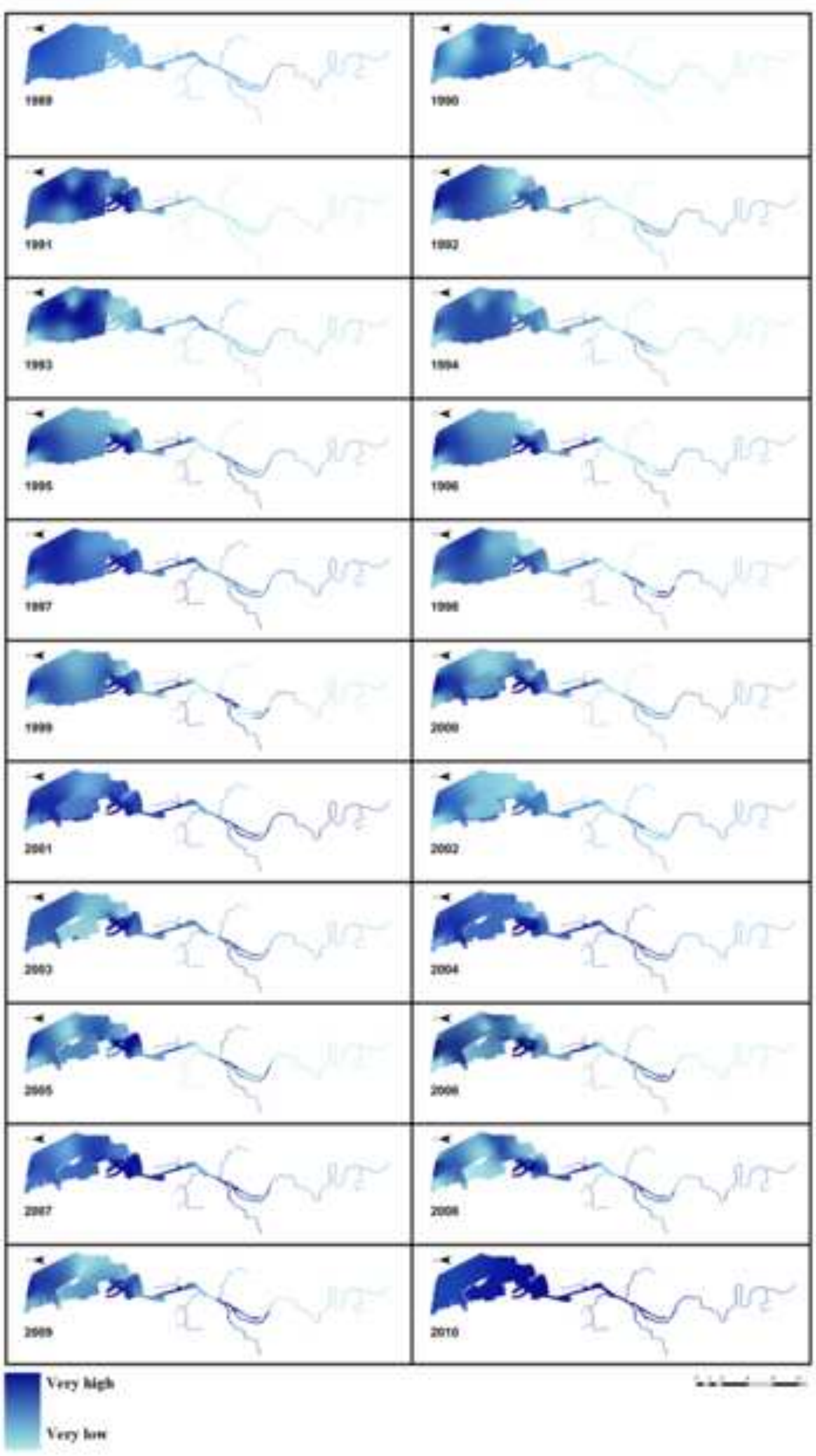


Figure 3

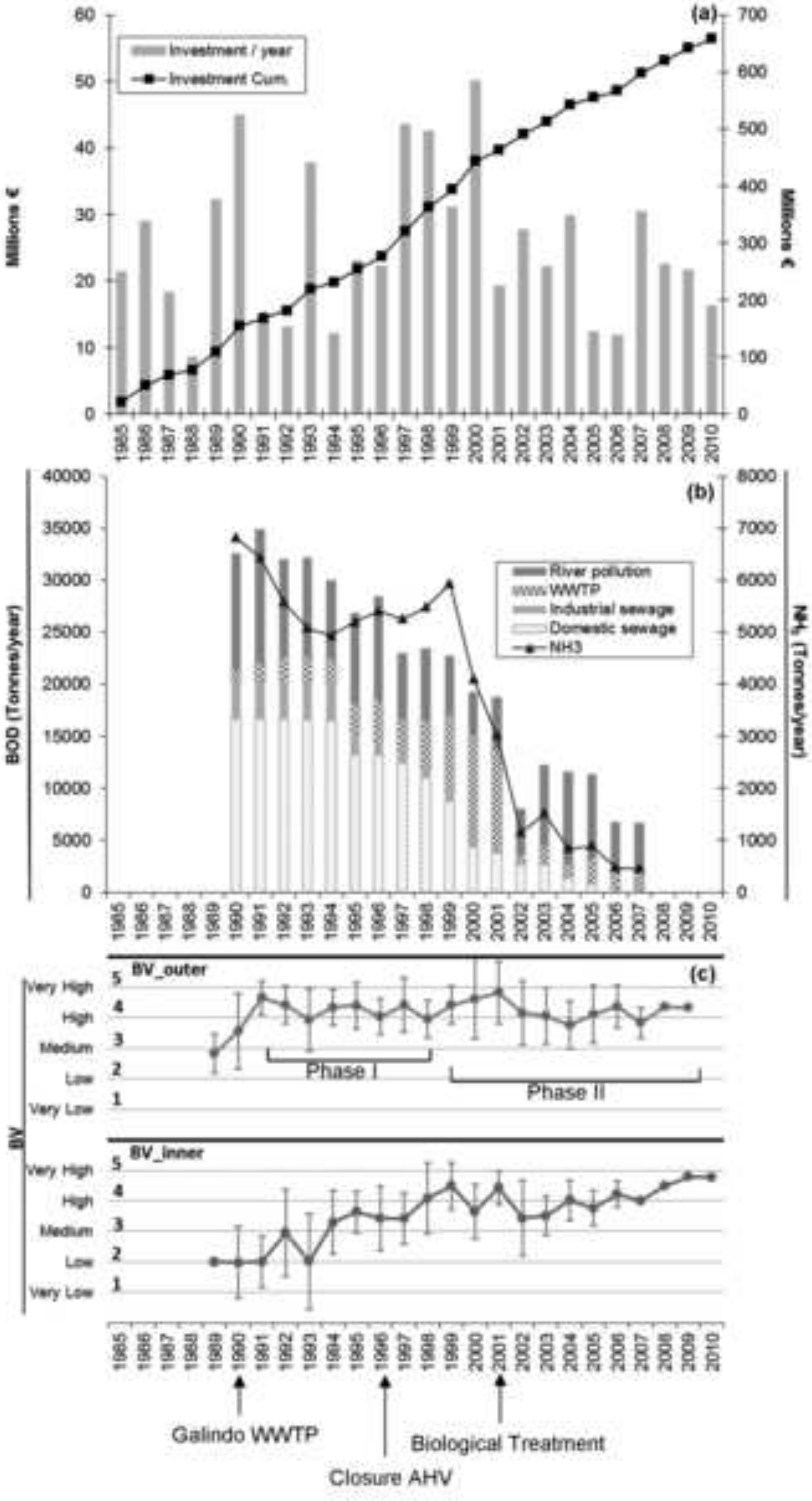
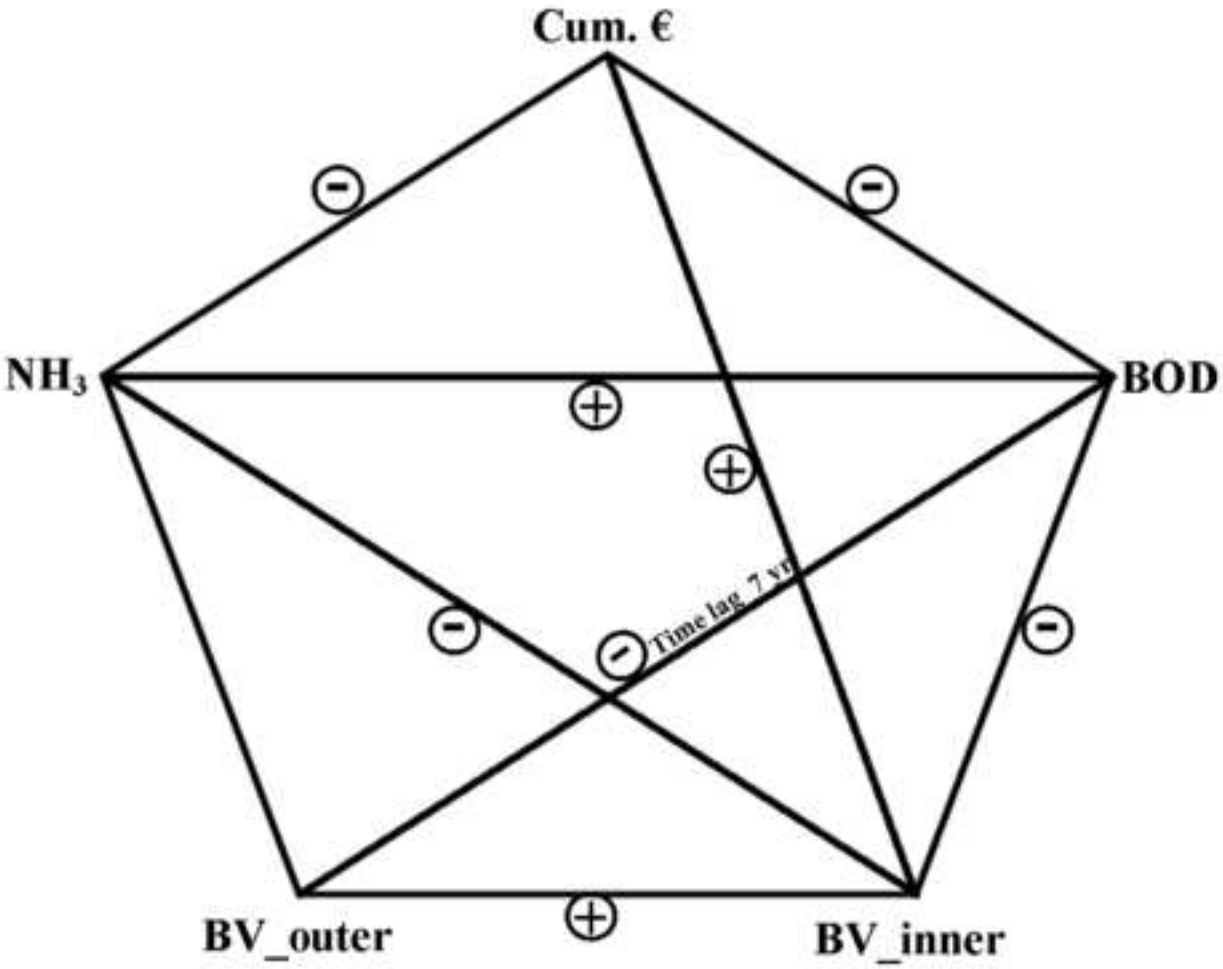

(a)
Millions €
Investment / year
Investment Cum.
0
10
20
30
40
50
60
100
200
300
400
500
600
700
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
(b)
BOD (Tonnes/year)
NH_3 (Tonnes/year)
River pollution
WWTP
Industrial sewage
Domestic sewage
NH3
5000
10000
15000
20000
25000
30000
35000
40000
1000
2000
3000
4000
5000
6000
7000
8000
(c)
BV
BV_outer
BV_inner
Very High
High
Medium
Low
Very Low
1
2
3
4
5
Phase I
Phase II
Galindo WWTP
Closure AHV
Biological Treatment

Figure 4



Figures:

Figure 1. Study area: Nervión estuary location at the western part of the Basque Coast together with a scheme of both inner and outer parts of the estuary. The localization of the main Galindo´s Waste Water Treatment Plant (WWTP) is also highlighted.

Figure 2. Biological Value evolution mapping: BV changes along the estuary throughout the sewage scheme period.

Figure 3. Investment and responses: (a) Cumulative Economic Investment (Cum. €); (b) Annual loads of Biochemical Oxygen Demand (BOD) and Ammonia nitrogen (NH_3) (t yr^{-1}), and (c) Averaged Total Biological Values and Standard Deviations (BV) per year; being 1= low and 5 = very high.
Main facts that occurred in the Nervión (Key: Phase I & II= External port widening Phases; WWTP= Waste Water Treatment Plant; AHV= Altos Hornos de Vizcaya)

Figure 4. Investment and responses correlation results summary: Per year and cumulative Economic Investment (€); Annual loads of Biochemical Oxygen Demand (BOD) and Ammonia nitrogen (NH_3) and Averaged Total Biological Values and Standard Deviations (BV) in inner and outer estuary.