



An Interdisciplinary Approach for Valuing Changes After Ecological Restoration in Marine Cultural Ecosystem Services

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Specialty section:

This article was submitted to
Marine Conservation
and Sustainability,
a section of the journal
Frontiers in Marine Science

Received: 14 May 2020

Accepted: 05 August 2020

Published: 21 August 2020

Citation:

Pouso S, Borja Á and Uyarra MC
(2020) An Interdisciplinary Approach
for Valuing Changes After Ecological
Restoration in Marine Cultural
Ecosystem Services.
Front. Mar. Sci. 7:715.
doi: 10.3389/fmars.2020.00715

Ecological restoration in marine ecosystems is considered strategic to recover environmental conditions and ecosystem services. However, the traditional single-discipline perspectives followed for analyzing the results of both restoration projects (focused in the analysis of biophysical changes) and valuation of ecosystem services (focused in economic valuation), do not provide useful theoretical frameworks when working with cultural ecosystem services, where socio-economic and environmental components are complexly interrelated. We propose an interdisciplinary approach for analyzing changes in cultural ecosystem services in restored marine ecosystems, based on the DAPSI(W)R(M) framework and following a social-ecological system approach. Our methodology considers environmental, social and economic elements that may be contributing to changes in the provision and demand for cultural ecosystem services in restored ecosystems. Our approach was tested in the Nerbioi estuary, a system that, after the implementation of a wastewater treatment plant at the end of the 20th Century, changed from being one of the most polluted estuaries in Europe to a nearly recovered system. Based on previous studies that have analyzed partial components of the restoration process and of the recreational ecosystem services, here we provide an interdisciplinary picture of the changes occurred in the last 25 years, directly linking the management measures adopted to an increase in human well-being. In the applied methodology, the three discipline domains (social, economic, and environmental) transcend each other to provide a new holistic view, completely different from what one would expect from the addition of the parts. In conclusion, this interdisciplinary approach provides a systematic framework for studying changes in cultural ecosystem services in restored systems, with a practical application for valuing human benefits as outcomes of marine restoration projects.

Keywords: ecological restoration, cultural ecosystem services, multiple values, social-ecological systems, marine blue spaces, integrated valuation

INTRODUCTION

Marine and coastal systems, through ecosystem services, provide many benefits to humans, contributing to our well-being (Barbier, 2017) and health (Borja et al., 2020). However, the overexploitation of resources and unsustainable environmental practices are generating the loss of biodiversity and degradation of ecosystems, which compromises the capacity of the natural systems to provide ecosystem services (Carpenter et al., 2006, 2009; Díaz et al., 2006; Outeiro et al., 2017). While the demand for ecosystem services continues to increase (Liu et al., 2010), their current global loss threatens human well-being.

Ecological restoration emerged as the most promising solution to recover natural assets and ecosystem services in human-degraded ecosystems (Elliott et al., 2007; Benayas et al., 2009), being an international priority for the coming decade, promoted by United Nations under the 'Decade on Ecosystems Restoration' (Cooke et al., 2019; Waltham et al., 2020). Ecological restoration encompasses "all the activities which seek to upgrade and improve the damaged area, recreate what had been destroyed, recover its use and restore its biological potential" (Bradshaw, 2002). Restoration of natural assets is recognized to improve biodiversity and contribute to achieving the good ecological status (Bullock et al., 2011; Everard, 2012). Also, it can be a first step to reverse declining trends in ecosystem services (Gómez-Baggethun et al., 2019). In the marine realm, where interactions between ecosystem and society are strong (Abelson et al., 2016), positive changes in ecological status after restoration actions could lead to an increase of provision of ecosystem services.

Despite the generally accepted idea of the possibility of recovering marine ecosystem services through ecological restoration, the few practical examples lead to important gaps between theoretical knowledge and practical verification (Abelson et al., 2016). Indeed, most studies for valuing the consequences of restoration projects analyze the changes in biophysical variables, but little attention is paid to the cascading changes in ecosystem services.

The consideration of the relationship between ecological restoration and marine ecosystem services in policies and management decisions is also scarce. In European legislation, ecological restoration is included in the two main Directives for the protection of aquatic biodiversity and environments: the Water Framework Directive (WFD; 2000/60/EC) and the Marine Strategy Framework Directive (MSFD; 2008/56/EC) (Borja et al., 2010b). Ecological restoration is considered as one of the ways to achieve the objectives of both directives: The objective of the WFD is "to achieve good ecological status for all water bodies by 2015 (now, 2021) and avoid deterioration, supporting the adoption of protection and restoration measures on aquatic ecosystems"; for the MSFD, the main objective is "to establish a framework to achieve or maintain good environmental status in the marine environment by 2020." Regarding marine ecosystem services, these are only mentioned in the MSFD, under the term "goods and services," but with no clear objectives associated to those.

The little consideration of ecosystem services in these policies and, consequently, in management decisions, is related to little comprehension of the interactions between biophysical and social elements that are required to provide ecosystem services (Carpenter et al., 2009; Costanza et al., 2017). Consequently, the critical role of marine ecosystem services for human well-being remains out of the spotlight, leaving them without clear protection measures and their true value remaining outside important economic decision-making processes (Millennium Ecosystem Assessment, 2005; Carpenter et al., 2009; Liu et al., 2010). From the three types of ecosystem services (i.e., provision, regulation-maintenance and cultural) considered by the Common international Classification of Ecosystem Services (CICES) (Haines-Young and Potschin, 2018), changes are relatively easily tracked for provisioning and regulating-maintaining services. However, the analysis of change in cultural services is more complex. As cultural services are the "non-material outputs of ecosystems that affect physical and mental states of people", analyzing changes also from a social perspective (e.g., user's behavior, perceptions, etc.) is mandatory (see Borja et al., 2020).

In this study, we study the consequences of ecological restoration projects in marine cultural ecosystem services. From a social-ecological system approach (Ostrom, 2007, 2009), we propose a way to perform an integrated valuation of marine cultural ecosystem services in restored areas, including environmental, social and economic factors in an interdisciplinary perspective.

VALUATION OF ECOSYSTEM SERVICES AFTER RESTORATION: FROM SINGLE-DISCIPLINE STUDIES TO MULTIDISCIPLINARY STUDIES

Ecological restoration success can be evaluated through changes in the provision of ecosystem services (Bullock et al., 2011; Borja et al., 2015). Furthermore, some authors consider ecosystem services valuation as a crucial step to evaluate the success of the investments done in restoration (Carpenter et al., 2009; De Groot et al., 2013).

Traditionally, valuations of ecological restoration and ecosystem services have been done following single-discipline perspectives. Ecological restoration success has been studied mainly through the analysis of changes in biophysical conditions (Martin and Lyons, 2018), while valuation of ecosystem services has been done focusing on monetary values (Gómez-Baggethun et al., 2010, 2014; Jacobs et al., 2017). Adopting the traditional single-discipline perspective to study the consequences of restoration in ecosystem services provides a partial and incomplete picture of the reality. Firstly, because restored ecosystems are part of complex systems, where strong interactions occur between nature and society (Abelson et al., 2016). Secondly, because valuation of ecosystem services should consider their multiple values domains (i.e., environmental, social and economic) (De Groot et al., 2002; Wang et al., 2013).

In recent years, scientists have advocated for applying social-ecological system concepts to ecological restoration and ecosystem services studies (Hobbs et al., 2011; Nassl and Löffler, 2015). The social-ecological system approach allows the establishment of linkages between people and nature, with emphasis on the idea that humans are part of nature (Berkes and Folke, 1998). This approach is especially relevant when the sociocultural part of the services (e.g., the cognitive processes involved such as emotions, perceptions, experience, local knowledge) has to be analyzed (Palomo et al., 2016).

Also, it is increasingly accepted that an integrated valuation approach is the most appropriate when working with ecosystem services (Gómez-Baggethun et al., 2014; Bark et al., 2016). The multiple and diverse elements involved, as well as the complex relationships between them, require the integration of multiple disciplines to study environmental, social and economic aspects of ecosystem services, consistently with the nature of the problems being analyzed (Liu et al., 2010; Costanza et al., 2017). This approach contemplates the multidimensional identity of ecosystem services (Martín-López et al., 2014) and advocates for a valuation perspective that combines the three ecosystem services valuation domains (i.e., environmental, social and economic domains) (Gómez-Baggethun et al., 2014) to support decision-making processes (Jacobs et al., 2016). It provides a more accurate valuation of ecosystem services than single-discipline approaches, and therefore, contributes to secure the sustainability of complex social-ecological systems in the long term.

Consequently, an integrated valuation of restoration should incorporate values of the three domains of ecosystem services (Martin and Lyons, 2018). Despite this clear prerequisite, there are still few examples of studies that followed a multidisciplinary approach to value the multiple domains of marine ecosystem services (García Rodrigues et al., 2017) and even less studies focusing on valuation of changes in ecosystem services after restoration. In February 2020, a search in Web of Science (WoS) identified a total of 185 articles published in the period 1997-2019 with the searching terms TS = ("integra* valu*") AND TS = ("ecosystem service*"). The first article was published in 2002. When the "marine" term was added to the search [AND TS = (marine OR coast* OR sea)], the results were reduced to 21, being the first article published in 2013. The combination of restoration with integral valuation of ecosystem services resulted in a total of 22 articles TS = ("integra* valu*") AND TS = ("ecosystem service*") AND TS = (restoration). The introduction of the marine term [AND TS = (marine OR coast* OR sea)], reduced the results to 2. This shows that there is a clear delay in research in marine ecosystem services compared to terrestrial ecosystems, and even more when it comes to research in recovery of marine ecosystem services in restored ecosystems.

The knowledge gaps regarding the relationships and interactions of the multiple elements involved in the provision of ecosystem services, and the few practical examples that could help to fill those gaps, make research in ecological restoration and valuation of ecosystem services a priority for marine research. The interdisciplinary study of ecosystem services in restored

marine ecosystems, which considers their three valuing domains, should be incorporated in the existing narrative (including legislation) of marine management.

ANALYSIS OF MARINE CULTURAL ECOSYSTEM SERVICES: COMBINING THE SOCIAL-ECOLOGICAL SYSTEM APPROACH WITH THE DAPSI(W)R(M) FRAMEWORK IN AN INTERDISCIPLINARY PERSPECTIVE

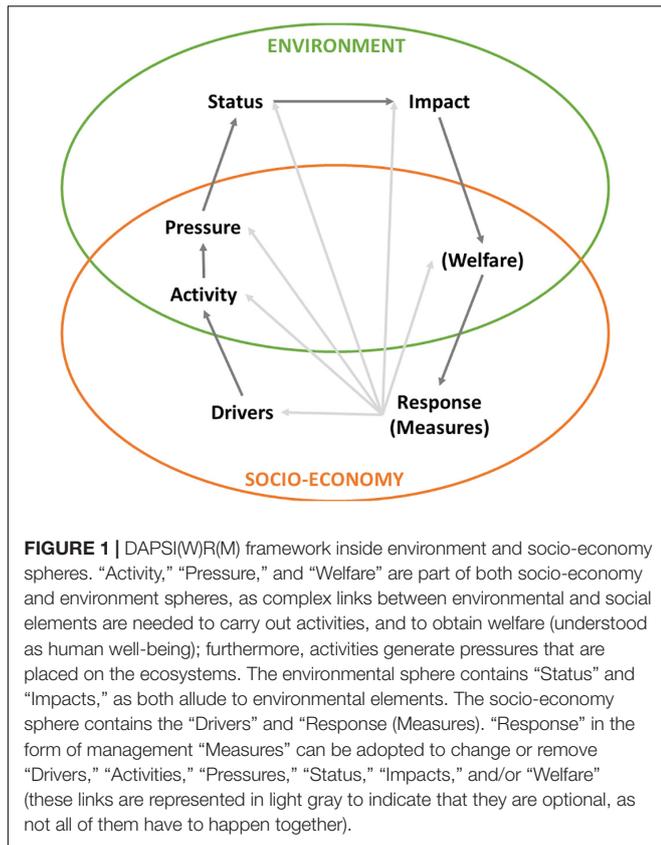
Any management measure in the complex marine environment needs to consider the interactions between ecosystem components and users, analyzing the key biophysical and socioeconomic aspects involved in it.

The DAPSI(W)R(M) framework, presented by Elliott et al. (2017), is a problem structuring framework, used in marine management to study, in an holistic way, the causes, consequences and responses to change. The DAPSI(W)R(M) framework comes from the development of the DPSIR (Drivers-Pressures-State-Impact-Response) framework, which has frequently been used to explain the degradation and posterior ecological restoration processes on marine ecosystems (OECD, 1993; Patrício et al., 2016a).

The DAPSI(W)R(M) framework is explained in detail in Elliott et al. (2017). In short, it considers that basic human needs (Drivers - D) are achieved through human activities (A). These human interventions create pressures (P) that lead to environmental alterations in the system (State changes - S). State changes can have an impact (I) on the environment (e.g., biodiversity) and societal welfare (W) (e.g., human benefits obtained through ecosystem services). In order to address the pressures, state changes and/or impacts created from a certain human activity, the society needs to adopt management measures [Response using Measures - R(M)]. Successful measures would prevent state changes and impacts on welfare and could also have a positive effect on other marine-based activities. The DAPSI(W)R(M) framework could represent a single activity, but as maritime activities are interconnected (e.g., the pressure generated by one activity could negatively affect other activity); the relations between the different activities can be represented by nesting several DAPSI(W)R(M) frameworks between them (Atkins et al., 2011; Elliott et al., 2017).

The evolution of DPSIR into DAPSI(W)R(M) allowed the incorporation of the ecosystem services concept to the framework, as Welfare matches with the human benefits obtained from ecosystem services. For highlighting how marine systems are social-ecological systems, the DAPSI(W)R(M) can be represented inside two main spheres: the environmental and socioeconomic spheres (see **Figure 1**). This representation helps to explain how impact (as degradation or as restoration processes) can have consequences for human well-being (in the form of ecosystem services).

Hence, here the perspectives of the three domains (environmental, social and economic) transcend each other



to form a new integrated approach, completely different from what one would expect from the addition of the parts.

INTEGRATED VALUATION OF CULTURAL ECOSYSTEM SERVICES IN RESTORED MARINE ECOSYSTEMS

The match between Welfare, in the DAPSI(W)R(M) framework, and the human benefits obtained from ecosystem services

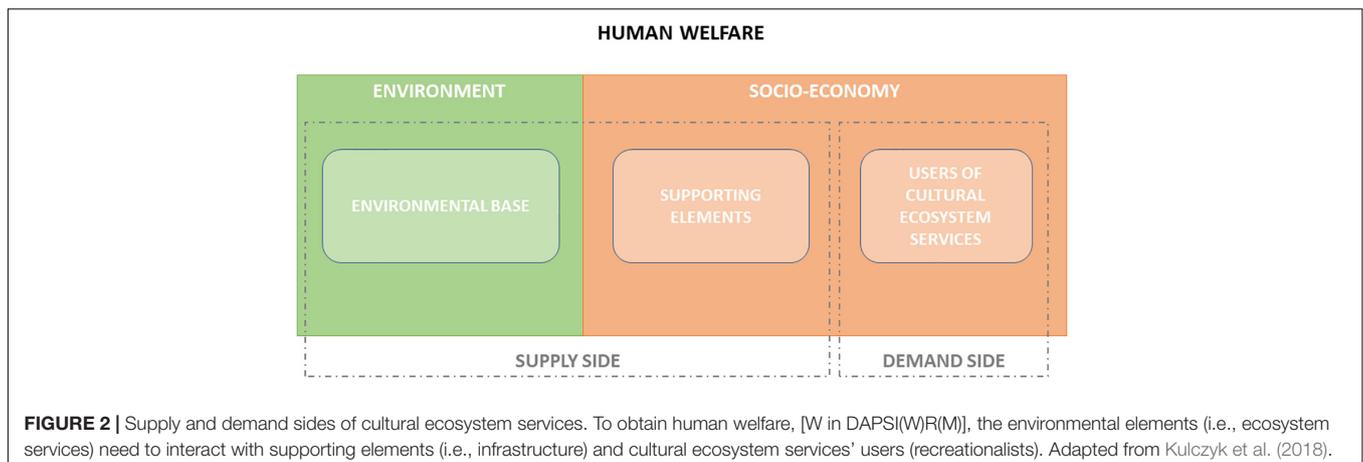
(Elliott et al., 2017), highlights the important role of social and environmental components in the provision of ecosystem services. Indeed, in **Figure 1**, Welfare is in both the environmental and the socio-economic spheres, matching the idea that benefits underpinned by ecosystem services are the result of complex combinations and interactions between natural components (i.e., natural capital) and human components (Chan et al., 2012b; Costanza et al., 2014, 2017).

The non-material character of the benefits provided by cultural ecosystem services makes them more difficult to study. Therefore, the analysis of the cultural ecosystem services is more approachable when focused on the human-ecosystem relationship that makes the benefits possible, instead of in the actual outcome or benefit.

When the objective is to study the changes in marine ecosystem services (e.g., after an ecological restoration process), apart from analyzing changes in environmental conditions, it is important to analyze if changes in social, economic and political aspects have happened, as these aspects also shape the benefits obtained from cultural services (Chan et al., 2012a). In other words, the evaluation of changes in Welfare (as described in DAPSI(W)R(M) framework) or human benefits after restoration should be done following an integrated valuation of ecosystem services. An integrated valuation is the one that considers environmental, social and monetary aspects (Villegas-Palacio et al., 2016) involved in the delivery of human benefits from ecosystem services.

Considering these ideas and based on the model designed by Kulczyk et al. (2018) for recreational ecosystem services, we present an interdisciplinary approach for studying the changes in cultural ecosystem services after restoration (**Figure 2**).

This model attends to both supply and demand side of ecosystem services (Burkhard et al., 2012). The supply side, or the capacity of a particular area to provide ecosystem services (Burkhard et al., 2012), has two main components, environmental base and supporting elements. Environmental base or natural capital includes environmental elements (i.e., physical-chemical and biological elements) that have a direct effect in the provision of specific ecosystem services. For example, in the recreational services of an estuary, the fish abundance



could be one of the key environmental elements. It is important to highlight that, from the ecosystem services' perspective, the improvement of the general conditions does not imply that the conditions required for specific human activities are also improved. Therefore, each ecosystem service studied in each case study requires to select the more appropriate elements that constitute their environmental base. The second part of the supply side are supporting elements, which include those general or specific recreational facilities that potentially can have an effect in cultural ecosystem services. For example, in a touristic beach, supporting elements can be the road network, aquatic sports facilities and other services (e.g., showers, toilets, platforms for access of disabled people), which affect the capacity of the area to provide recreational services.

Regarding the demand side, it focuses on the users (or consumers) of cultural ecosystem services. The objective is to understand the current use of the services, collecting information on users' perceptions, behavior, and values (e.g., monetary) associated to the benefit. In order to check if use has changed due to environmental changes, historical data will be collected (e.g., number of users before and after restoration). A key aspect when analyzing changes in ecosystem services in a restored ecosystem is to analyze changes registered in both the supply and demand sides. Only when changes in the service demand are proved to be related to changes in the environmental base, will we be able to confirm that changes in ecosystem services are an outcome of ecological restoration measures.

Hence, the integrated valuation will be completed when: (i) the capacity and supply of ecosystem services has been evaluated; (ii) the users' demand is set, through their perceptions and behavior toward the services provided by the ecosystem; and (iii) the monetary (or non-monetary) values of the benefits are determined, completing the chain of the three domains to evaluate if the restoration of a marine system has resulted in a recovery of the environmental values and socio-economic benefits.

PRACTICAL EXAMPLE OF THE INTERDISCIPLINARY APPROACH: THE NERBIOI ESTUARY

Description of the Ecosystem and Restoration Processes Under the DAPSI(W)R(M) Framework

The Nerbioi estuary is located in the inner Bay of Biscay, on the coast of the Basque Country, Spain (Figure 3). Nine municipalities are located along the two banks of the estuary, including the city of Bilbao, and comprise a total population of 695,020 inhabitants in 2019¹.

From the mid-19th Century, the urbanization, industrial (i.e., mining, steel and chemical industries), and port developments caused a deep change in the estuarine morphology and degraded

its environmental health status. In the second half of the 20th Century, the Nerbioi estuary became the most polluted estuary in northern Spain and one of the most polluted in Europe (Cearreta et al., 2000). The continuous discharges of untreated urban and industrial wastes caused the accumulation of pollutants and the organic enrichment of the sediments and the water column, the reduction of the concentration of dissolved oxygen in the water column (with episodes of hypoxic and anoxic conditions in the inner estuary) and the general degradation (even absence) of the biological communities (Belzunce et al., 2001, 2004b; Gorostiaga et al., 2004; Borja et al., 2006).

Also, the intense development of urban, industrial and port activities in the estuarine banks, in need of space for placing their infrastructures, transformed the estuary into a narrow navigable tidal channel (Cearreta et al., 2004), with a clear differentiation of two zones: the inner part, a highly stratified channel of 15 km length, that crosses the city of Bilbao; and the outer part, also known as the "Abra," a semi-enclosed coastal embayment of 30 km² (Leorri et al., 2008; Irabien et al., 2018).

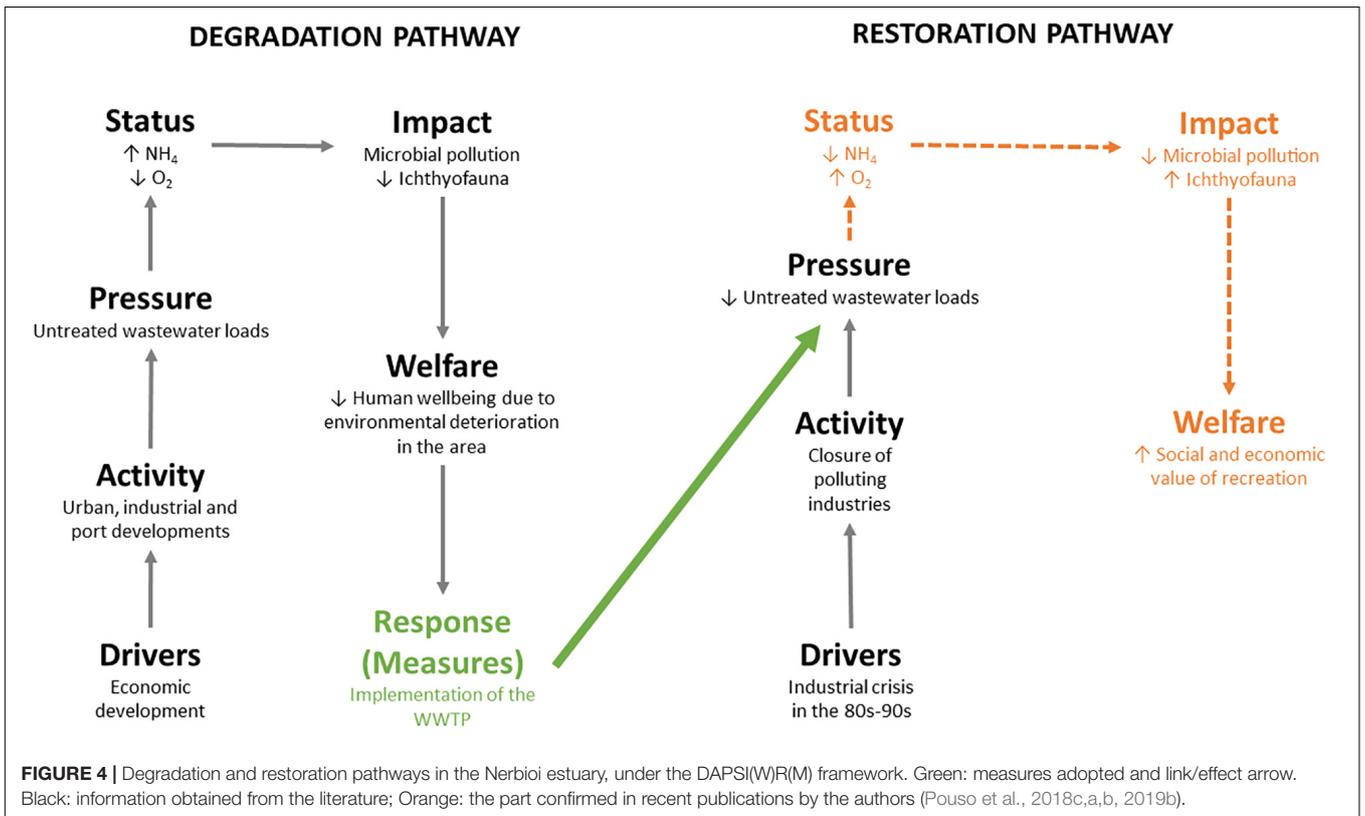
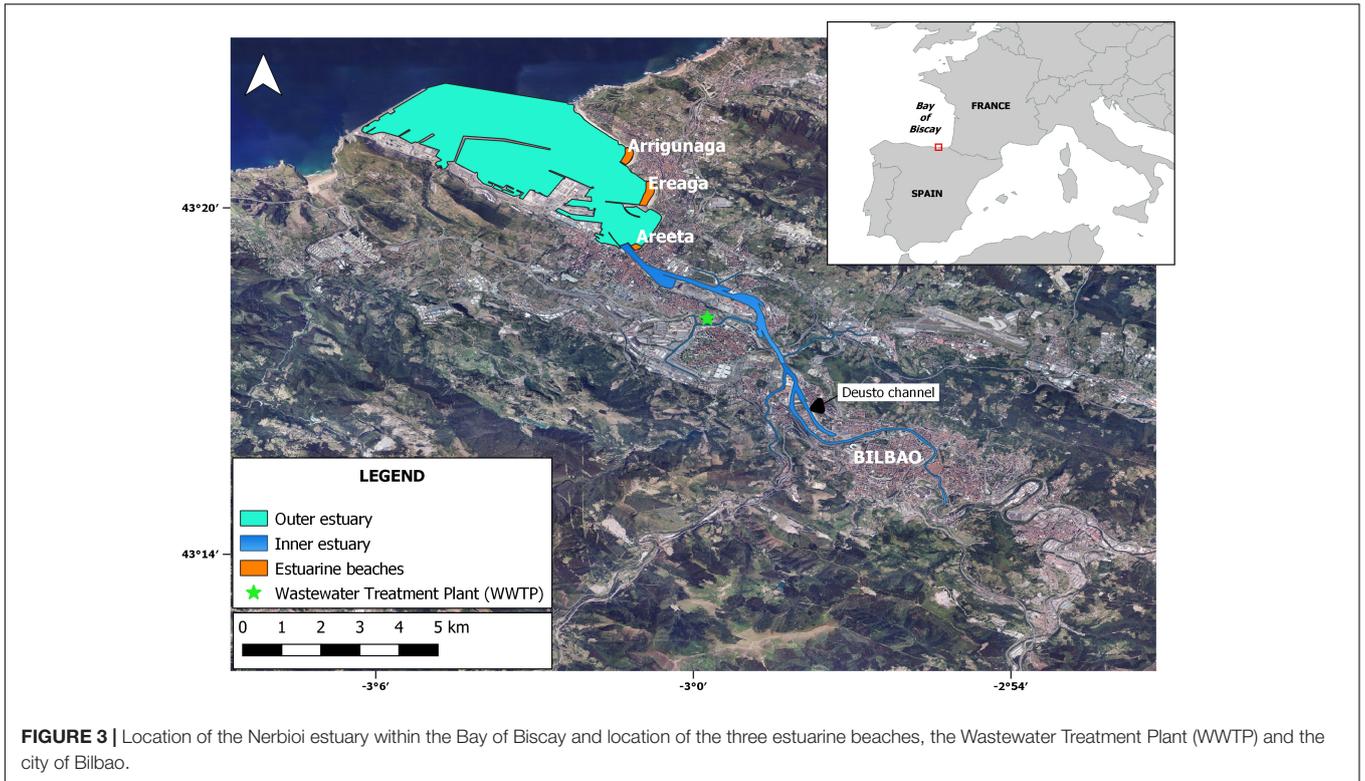
In 1979, the Sanitation Scheme was approved by the local authorities, with the aim to restore the esthetics, sanitary and ecological conditions of the estuary, and to achieve a water quality standard of 60% oxygen saturation (Pascual et al., 2012). The Nerbioi's recovery has been gradual, responding to three milestones (Borja et al., 2010a): (i) in 1990, the implementation of the Wastewater Treatment Plant (WWTP) of Galindo, with physical and chemical treatments; (ii) in 1996, the closure of the highly polluting iron and steel industry "Altos Hornos de Vizcaya" (AHV); and (iii) in 2001, the addition of the biological treatment in the WWTP. The closure of industries, the WWTP implementation, and the limitations imposed by more restrictive environmental policies caused a decline of metals, organic compounds and fecal pollution inputs into the estuary, reducing the pollutant concentrations in estuarine waters and sediments (Belzunce et al., 2004b,a; García-Barcina et al., 2006; Borja et al., 2016; Irabien et al., 2018). This resulted in the recovery of, among others, benthic communities (Borja et al., 2006) and demersal fishes (Uriarte and Borja, 2009), as reflected in the increase of the general biological value within the estuary (Pascual et al., 2012).

Despite the many scientific publications confirming that the general environmental conditions in the estuarine waters have improved after restoration, how the adopted restoration measures caused changes in ecosystem services has not been studied until recently (Pouso et al., 2018c,b, 2019b). These studies focused on specific values of ecosystem services (i.e., social or economic), but this is the first attempt to evaluate, following an integrative approach, how cultural ecosystem services recovered in the restored Nerbioi estuary.

To understand this process (how ecosystem restoration may translate into ecosystem service improvement), the degradation and restoration processes of Nerbioi estuary, presented above, have been conceptualized using the DAPSI(W)R(M) framework (Figure 4), differentiating between Drivers vs. Activity, Impact vs. Welfare, and Response vs. Measures.

In order to understand how aquatic restoration activities in the Nerbioi estuary may affect human well-being, two recreational activities have been selected for applying the framework: bathing

¹https://www.eustat.eus/estadisticas/tema_268/opt_1/tipo_1/ti_Estadistica_municipal_de_habitantes/temas.html#el



waters in beaches and recreational fishing. These activities were selected due to their direct dependency on or contact with water.

Changes in Recreational Ecosystem Services After Restoration Measures

To understand the flow (or lack of it) between biophysical and human components shaping the supply and demand sides of ecosystem services, the model introduced in **Figure 2** was applied to the Nerbioi estuary case study. Thus, the changes in the two recreational activities were analyzed, attending to the supply and demand sides that shape the benefit (**Figure 5**).

To evaluate the changes in the environmental base (**Figure 5**), we analyzed temporal trends on environmental conditions, using data collected through monitoring programs. The environmental parameters selected were, for recreational fishing, transparency through Secchi disk depth, oxygen saturation, ammonia concentration, fish richness and abundance; and for beach recreation, transparency through Secchi disk depth and concentration of fecal bacteria [for details, see Pouso et al. (2018b; 2018c)] These parameters were chosen due to their critical role for allowing the two recreational activities. For recreational fishing, we focus on two chemical parameters (oxygen saturation, ammonia concentration) linked to the recovery of the fauna in the estuary (Borja et al., 2006). For beach recreation, we focus on the concentration of fecal bacteria, the parameter used in European legislation to determine the quality of bathing waters; and on water transparency, which is a characteristic considered by beach users to judge water quality (Peng and Oleson, 2017).

There has been a significant improvement in water conditions along the estuary, where oxygen saturation increased, and ammonium concentration decreased throughout time (**Table 1**), while changes in water transparency were not statistically significant. Fish richness significantly improved in the inner estuary (minimum 2 taxa in 1990, 1994 and 1997, and maximum 13 taxa in 2015) and in the outer estuary (minimum 4 taxa in 1995 and 1998 and maximum 14 taxa in 2011). Regarding fish abundance, the increase has also been important and statistically significant in both the inner and outer estuary. When comparing inner and outer results from **Table 1**, it is important to note that since 2010 in the outer estuary the number of sampling stations are reduced from two to one, and in the inner estuary, there are three and have been monitored since 1990. Also, that the inner estuary has recovered from a more degraded overall state than the outer estuary.

In the three estuarine beaches, transparency has significantly increased in all of them. The microbial concentration, for which monitoring is mandatory for bathing waters according to EU and national legislation (European Commission, 2006; Spanish Government, 2007), show decreasing trends (**Table 2**). The number and proportion of water samples that exceeded the safety threshold decreased following the implementation of more restrictive legislation in 2008 (**Table 2**).

For analyzing changes in supporting elements (i.e., general or specific recreational facilities), we compared orthophotos from 1983, 1995, 2001, 2013, and 2018 retrieved from GeoEuskadi².

Visual comparison of orthophotos was done at first, to detect the locations where the most significant changes have occurred. Focusing on those selected locations, the changes in the available area have been calculated using QGIS (QGIS Development Team, 2009). In the outer Nerbioi, the most important change has been the extension of the industrial port facilities in the left bank of the estuary, which (i) reduced the shoreline accessible to the people (e.g., recreational fishers), as most of the shoreline is now under the domain of the Port Authority and (ii) land reclamation that reduced the extension of the estuary. From the comparison of the orthophotos, we conclude that there has been a loss of circa 3.4 km² (i.e., >16%) of the water extension between 1983 and 2018, due to the construction of industrial port facilities (**Figure 6A**). Also, there are certain aquatic areas under the management of the Port Authority where only port activities are allowed. This increase in port facilities in the left bank caused a reduction of the accessible shoreline of ~3 km between the villages of Zierbena and Santurtzi (**Figure 6A**). In the right bank of the estuary, the most important change has been the construction of a recreational port (1998) and its recent enlargement with cruise mooring facilities (first mooring facility started operating in 2006 and the second in 2015) (**Figure 6B**). The three estuarine beaches, which are located in the right bank of the outer estuary, have not suffered intense morphological changes. While the road link has not been significantly altered, public transport connection has improved. The old train line was renewed to a metro line in 1995, which increased the train frequency and added new stations. The locations of the metro stations closer to the three beaches did not change significantly.

In the inner estuary, the main change has been the recent opening of the Deusto channel, a morphological change in the estuary that happened in 2018-2019. The environmental effects of this action have not been yet assessed.

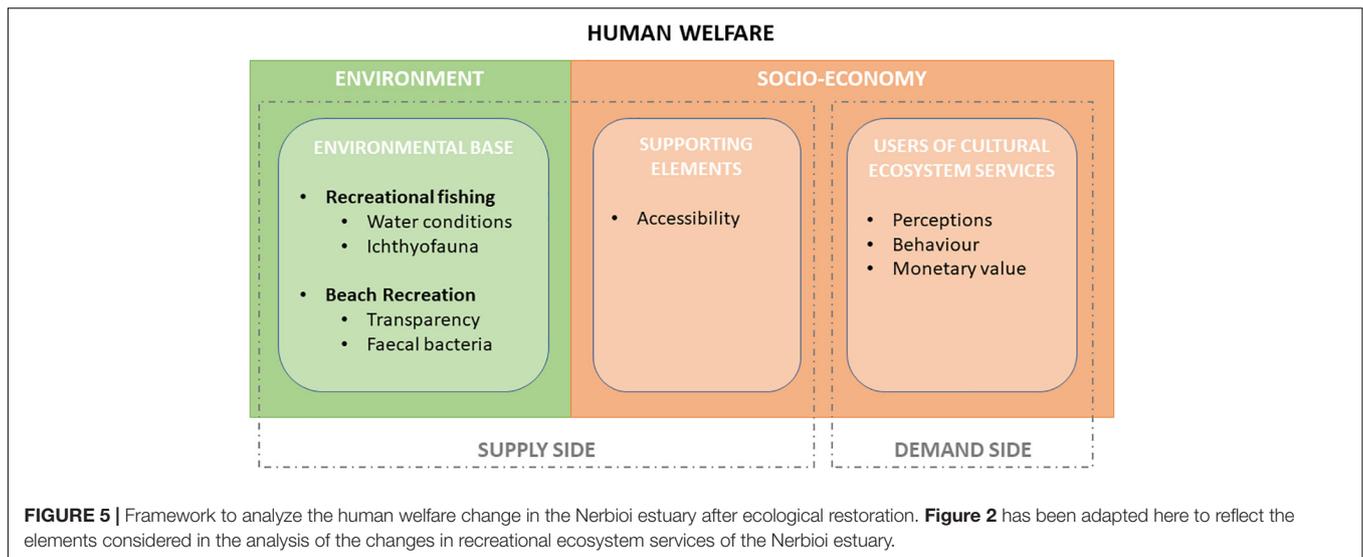
For analyzing the demand side, available data on the current and past number of beach recreationalists and recreational fishers were collected [for details, see Pouso et al. (2018a, 2019b)]. Data on the number of beach visitors were collected in summer period (from June to September) by the regional Government of Bizkaia since 2013. Due to their good accessibility and location, close to Bilbao, the three beaches in Nerbioi receive a high number of recreationalists in summer. Indeed, from 2013 to 2019, Ereaga has ranked at the TOP 3 of most visited beaches of the region every year³.

There were no records on the number of recreational fishers who have been fishing inside the estuary in the last three decades [for details, see Pouso et al. (2018b)]. Therefore, the number of recreational fishing licenses issued in the nine municipalities located along the estuary was used as proxy.

Since 1999, when licenses became compulsory for practicing recreational fishing, the number of terrestrial fishing and spearfishing licenses first followed an increasing trend in the region of Bizkaia (from 19,038 licenses in 1999 to 41,517 in 2011), and then a decreasing trend (with 33,606 in 2015) (Basque Country Government, personal communication). The proportion of licenses belonging to inhabitants of the nine

²<http://www.geo.euskadi.eus>

³https://www.bizkaia.eus/Ingurugiroa_Lurraldea/Hondartzak/listadoplayas.asp



estuarine villages has remained stable at around 56–60% of the total licenses issued in Bizkaia. The high contribution of Nerbioi villages to the total amount of licenses in the region goes in line with population data, as the nine Nerbioi villages account for ~60% of the total population in the region (Eustat, 2017).

The current use of the two recreational activities was assessed through two dedicated questionnaires, designed and distributed in 2016. Two anonymous questionnaires were used to analyze the changes in social behavior and perceptions, as well as to collect the necessary information to perform monetary valuations of the activities (Pouso et al., 2018a,b,c, 2019b). The interviewer explained the voluntary nature of the participation and the need for participants' consent before responding to the questionnaire. Data management was done according to the Spanish Law 15/1999 on Protection of Personal Data⁴. Some of the most remarkable results of the questionnaires, mainly related to recreationalists profile, changes in behavior and perceptions on water quality, are summarized in **Tables 3, 4**. Further details can be found in Pouso et al. (2018b; 2018c).

Relaxation was one of the main reasons most frequently mentioned by users to recreate in the Nerbioi estuary, while spending time with friends and relatives was also important for recreational fishers (**Tables 3, 4**). This reason was not mentioned among beach goers so often (reasons such as sunbathing and bathing ranked higher) but most of them (>72%) visited the beach with friends or relatives.

Surveys also revealed that users' behavior is influenced by environmental conditions. Thus, percentage of those getting into the water is higher in beaches with better water conditions (higher transparency and lower microbial concentration) (**Table 4**) and fishing is more common in areas that have maintain better conditions (outer estuary over inner estuary) (**Table 3**).

Behavior changed as a consequence of ecological restoration. Among recreational fishers, results suggested that fishers

progressively extended their effort to the inner estuary, responding to the improvements in water quality, fish richness and fish abundance [**Table 3** and Pouso et al. (2018b)]. A decrease in the activity in certain areas of the outer estuary was detected by the questionnaire, which was linked to the extension of the industrial port facilities in the left bank (Pouso et al., 2018b). Beach recreationalists were asked to rate the probability that they would return to beaches if water quality was to worsen (Pouso et al., 2018c). Results revealed that most of them would not come back if water quality worsens; and together with the importance placed to aquatic activities as a motivational factor to visit beaches, it was concluded that water quality improvement has been important to the development of the beach recreation. Although most beach visitors bathe in Nerbioi beaches; among the ones that do not, the perceived poor quality of the water was the most frequently mentioned reason (Pouso et al., 2018c).

The study of perceptions revealed that users are able to perceive water improvements. Among experienced beach visitors' users (>5 years visiting the beach), most of them perceived that water conditions have improved (**Table 4**) and most of them believe that the main reason is the implementation of the wastewater treatment (Pouso et al., 2018c). Recreational fishers also perceived an improvement in water conditions (**Table 3**) linked to the wastewater treatment, and most of them believe that the WWTP had positive consequences for the recreational activity (Pouso et al., 2018b).

The travel cost analysis performed to estimate the value of the two activities, estimated a current aggregated-use value of 4.65 M€ year⁻¹ (**Tables 3, 4**). This amount covers all the maintenance and service costs associated to beach recreation (e.g., sampling and analysis of bathing waters, rescue services) and an important amount of the sewage system running costs [more information available in Pouso et al. (2018a, 2019b)].

Following an interdisciplinary approach, it has been shown that the restoration investment resulted in a recovery of the ecosystem components (environmental domain), which provided benefits for human well-being (social domain), in terms of

⁴Law 15/1999 on Protection of Personal Data (<https://www.boe.es/eli/es/lo/1999/12/13/15>).

TABLE 1 | Trends over time in the general physicochemical and biological conditions of the Nerbioi estuarine waters, expressed as linear regression (Coefficient, Standard Error, and R²) and minimum and maximum data.

	Outer estuary				Inner estuary			
	Coef. sign	R ² (p-value)	Min (year)	Max (year)	Coef. sign	R ² (p-value)	Min (year)	Max (year)
Secchi disk depth (m) (1994–2015)	+	0.118 (n.s.)	1.66 (2005)	4.33 (2015)	+	0.046 (n.s.)	0.60 (2004)	1.48 (2002)
Bottom oxygen saturation (%) (1994–2015)	+	0.221 (0.032)	84.6 (1997)	101.1 (2003)	+	0.755 (<0.001)	30.5 (1994)	87.4 (2014)
Surface Ammonia (μmol l ⁻¹) (1994–2015)	-	0.530 (<0.001)	3.6 (2015)	93.6 (1997)	-	0.387 (0.002)	9.0 (2015)	495.0 (1994)
Fish richness (1990–2015)	+	0.624 (<0.001)	4 (1995, 1998)	14 (2011)	+	0.745 (<0.001)	2 (1990, 1994, 1997)	13 (2015)
Fish abundance (Ind Ha ⁻¹) (1990–2015)	+	0.191 (0.025)	21 (2011)	2147 (2013)	+	0.210 (0.015)	6 (1990)	2579 (2013)

Values are calculated as yearly means in inner and outer sampling stations using data collected by URA (Basque Water Agency) for Secchi disk depth, Oxygen Saturation and Ammonia concentration; and data collected by CABB (Consorcio de Aguas de Bilbao Bizkaia) for fish richness and fish abundance. The yearly means were calculated using data from 3 sampling points for the inner estuary, and 2 sampling points for the outer estuary (reduced to a single sampling point after 2010). Key: m = meters; Coef. sign = sign of the coefficient in the regression equation; Min = minimum yearly mean value; Max = Maximum yearly mean value.

enhancing the provision of cultural ecosystem services, which leads to covering the costs of most of the investments and maintenance of the services (economy domain). This work provides a holistic view to explain how the efforts done in reverting a degraded situation resulted in human benefits in the form of cultural ecosystem services.

DISCUSSION

In this paper, an interdisciplinary approach has been applied to analyze changes in marine cultural ecosystem services after ecosystem restoration, in an integrative way, including environmental, social and economic domains. The approach relies on the DAPSI(W)R(M) framework, a common framework for communicating policy-relevant information on marine management (Atkins et al., 2011), and on integrated methodologies for valuation of recreational ecosystem services (Kulczyk et al., 2018). The interdisciplinary approach has been tested in the Nerbioi estuary, with a focus on recreational services, but it could be adopted to analyze changes in other cultural ecosystem services (e.g., education and training, scientific knowledge, experiences, esthetic value). For the last three decades, the ecological restoration of the Nerbioi estuary has been studied only from an environmental perspective. Five articles published in the last two years analyzed partial aspects of the recovery of recreational ecosystem services in the estuary, including environmental, social and economic domains. In this article, all those partial results from the three domains have been integrated with new information, in order to provide an holistic view of the change occurred in the recreational ecosystem services, and which can serve as guide in other restored coastal areas.

First, it is important to perform an extensive analysis of the environmental base, considering the specific biophysical characteristics that determine the capacity of the ecosystem to provide certain cultural services. Those characteristics might have changed after restoration, either directly (i.e., the change was an objective of the restoration project) or indirectly (as a consequence of the change in another biophysical characteristic). The biophysical characteristics to be analyzed should be chosen considering the particular characteristics of the system, and the ecosystem services under study. Ideally, the biophysical data will cover pre- and post-restoration periods. Despite the successful long-term monitoring networks in marine ecosystems worldwide (Borja et al., 2016), there are many ecosystems still lacking appropriate monitoring (Patrício et al., 2016b). There is a need to improve monitoring of marine areas, especially of those considered to be “ecosystem services hotspots.” Also, it is important to put into value the information provided by existing monitoring networks, and the indispensable information they provide for the study of trends and for early detection of changes. Establishing and/or maintaining long-term monitoring networks in restored ecosystems is necessary to be able to link environmental changes to subsequent changes in ecosystem services demand. In the Nerbioi estuary, long-term information on biophysical parameters was available, as the estuary has been

TABLE 2 | Trends in the condition of bathing waters over time and across three beaches (from innermost to outermost beach: Areeta, Ereaga, and Arrigunaga; see **Figure 3**), expressed as linear regression (Coefficient, Standard Error, and R²) and minimum and maximum data.

	Areeta					Ereaga					Arrigunaga							
	n	>limit	Coeff. Sign	R ² (p-value)	Min (year)	Max (year)	n	>limit	Coeff. sign	R ² (p-value)	Min (year)	Max (year)	n	>limit	Coeff. sign	R ² (p-value)	Min (year)	Max (year)
Faecal coliforms (1985–2007) ^A (MPN)	No data	No data	No data	No data	No data	No data	322	63	–	0.3856 (n.s.)	100 (2006)	1548.1 (2000)	160	33	–	0.4932 (n.s.)	100 (2006)	2133.29 (2001)
Escherichia coli (2008–2016) (MPN)	164	22	–	0.1234 (n.s.)	82.35 (2016)	804.67 (2008)	322	11	–	0.2353 (n.s.)	22.37 (2012)	710.47 (2008)	157	9	–	0.1416 (n.s.)	36.43 (2009)	730.33 (2008)
Secchi disk depth (1999–2016)			+	0.78 (<0.001)	0.77	1.87			+	0.66 (<0.001)	1.25	2.8			+	0.26 (0.03)	1.94	3.05

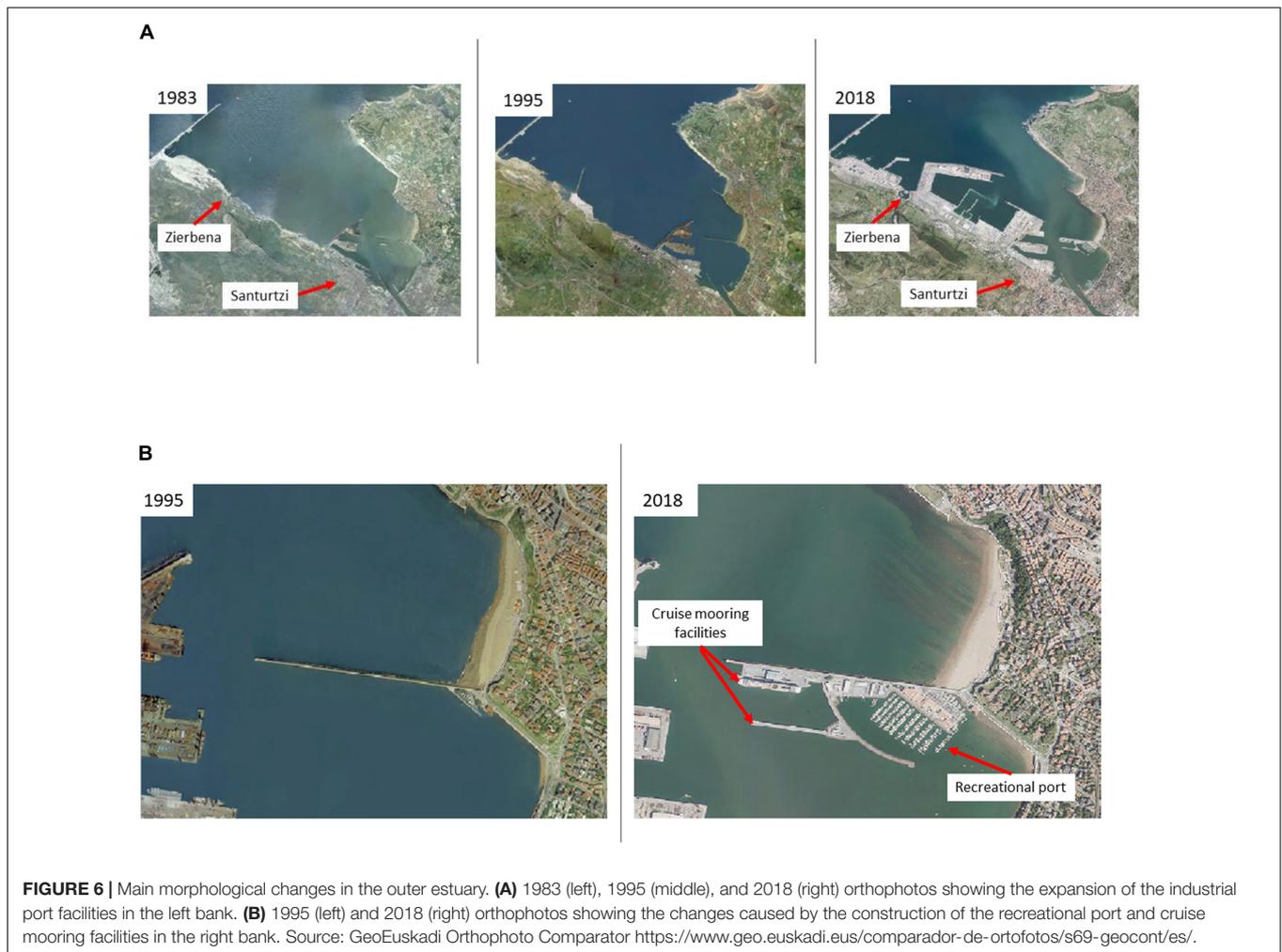
Regressions are calculated with yearly mean values, using fecal coliforms and Escherichia coli data collected by the Basque Government during bathing season (May–September); Secchi disk depth data collected by CABB (Consortio de Aguas de Bilbao Bizkaia). Key: n = number of samples; > limit = number of samples above threshold (>2000 MPN 100 ml⁻¹ for fecal coliforms (Directive 76/160/CEE⁶ European Commission (1976), Council Directive 76/160/EEC of 8 December 1975 concerning the quality of bathing water) and >500 MPN 100 ml⁻¹ for Escherichia coli (Law 2006/7/EC⁶ European Commission (2006), Directive 2006/7/EC of 15 February 2006 concerning the management of bathing water quality and repealing Directive 76/160/EEC); MPN = Most Probable Number; m = meters; Coef. sign = sign of the coefficient in the regression equation; Min = minimum yearly mean value; Max = Maximum yearly mean value. Fecal coliform sampling in Arrigunaga started in 1992.

monitored since 1989 by two monitoring networks, Bilbao-Bizkaia Water Consortium (CABB) and the Basque Water Agency (URA). The availability of information facilitated the retrieval of the specific parameters we needed to perform the cultural ecosystem services evaluation.

Supporting elements, together with the environmental base, constitute the supply-side of recreational ecosystem services (Kulczyk et al., 2018). In restored ecosystems, the analysis of supporting elements is a crucial step, in order to elucidate if changes in human well-being can be linked to: (i) improvements in the environmental conditions, (ii) changes in supporting elements or (iii) a combination of changes in both. In our case study, the analysis of supporting elements focused in accessibility, known as a crucial element for making recreational ecosystem services reachable (Paracchini et al., 2014). The analysis demonstrated that supporting elements can have an influence on current use patterns; e.g., recreational fishers in Nerbioi estuary do not fish as much as expected in the area with the best environmental conditions due to accessibility limitations (Pouso et al., 2018b).

Once the changes that restoration generated in the supply-side have been analyzed, it is time to check if this translates into a change in the demand-side, i.e., changes in use. This part of the analysis could be challenging, as usually social data are scarcer than data on environmental and supporting elements. In the Nerbioi estuary, the abundant information on environmental parameters was not reflected in socioeconomic aspects. There was little information on recreational fishing activity and beach use that covered the entire restoration process period. Visitors to the beaches were only counted systematically since 2013. For recreational fishing, the only proxy available was the number of licenses. However, living in a nearby village and having the fishing license does not mean that they practice the activity inside the estuary. Similarly, people from other villages outside the estuary can fish there. The available tourism-related information (e.g., number of visitors to nearby villages, number of arrivals through cruises), was not considered appropriate for the objective of the study, as it did not have a straightforward relation with the two recreational activities under analysis. However, these sources might be very useful depending on the aim of the study, e.g., if the focus is to analyze general changes on recreational ecosystem services.

To overcome this problem, socioeconomic information was collected using questionnaires. Face-to-face questionnaires are frequently used in ecosystem services research, usually to collect information on current use and social perceptions (Martín-López et al., 2007, 2012). In Nerbioi estuary, questionnaires were also used to compile information about past use and behavior, in order to check if demand has changed after restoration. The methodology is opened to include any stakeholder considered crucial (e.g., inhabitants in the nearby villages, policymakers, recreation and tourism industries), which will be dependent on the case study. In the Nerbioi estuary, the demand-side analysis was performed by distributing questionnaires exclusively to current recreational users of the estuary. This decision was adopted to increase the efficiency on the questionnaire distribution. However, it also represents a limitation as we could



not collect the perceptions of potential users that despite having a good access, do not recreate in the area (e.g., inhabitants of the nearby villages who move farther to recreate, past users that for some unknown reason have stopped recreating in the area, etc.).

Responses to the questionnaire supported our hypothesis that restoration efforts in the Nerbioi estuary led to higher provision of cultural ecosystem services (Pouso et al., 2018c,b). Generally, questionnaire results revealed that recreational users perceive the improvements in the water conditions. Users perceive environmental trends and adapt their behavior accordingly (fishers moving to inner estuary to fish, beaches visitors revealing that the water improvement has been key for them to decide to visit estuarine beaches). Certain concerns exist among recreationalists, e.g., beach visitors that do not bathe due to the perception of poor water quality. Considering the improvements on environmental conditions, the continuation of negative perceptions could be linked to the memory of past conditions (Pouso et al., 2018c). Also, there might be potential users that do not recreate here due to the negative perception they still have on the past water conditions. This will be the case of fishers that despite living nearby, they still prefer fishing in other areas far away; also, the case of beach goers who indicated that

bathing is one of the main reasons to go to beaches, but they do not bathe in estuarine beaches due to the negative perception they have on the water conditions. This indicates how difficult is to change negative perceptions associated to past situations.

The interdisciplinary approach used in this research allows us to study changes in the multiple values (i.e., intrinsic, instrumental and relational values) that cultural ecosystem services have (Chan et al., 2012b, 2018). Traditionally, studies on ecosystem services have focused on assessing the instrumental values [or “things that are means to some external end” (Himes and Muraca, 2018)], and this has been done through diverse monetary valuation techniques (Turner and Schaafsma, 2015). In Nerbioi, the instrumental values of the two recreational activities were assessed (Pouso et al., 2018a, 2019b) using the Travel Cost Method (Parsons, 2003), which has been extensively used to value recreational services. The information that econometric tools provide can be valuable; still, ecosystem services should not be valued exclusively with monetary techniques as their result is insufficient to represent the many ways in which people benefit from nature (Chan et al., 2012b). In the Nerbioi estuary, the monetary valuations revealed that recreational activities cover an important percentage of costs for maintaining the environmental

TABLE 3 | Summary of the main characteristics and results of the questionnaires distributed among recreational fishers in the Nerbioi estuary.

Recreational fishing	
Distribution Details	
<i>n</i>	146
Distribution	January–September 2016
Socioeconomic characteristics	
Age	
<i>Mean ± SD</i>	51 ± 14
Gender	
<i>Women</i>	6.8%
<i>Men</i>	93.2%
Main motivations to practice the recreational activity (3 main motives)	
Relaxation	75.3%
Be with friends or relatives	41.1%
To practice outdoor activities	31.5%
Why did you choose this recreational spot today? (3 main reasons)	
Proximity to home	35.6%
Habit	33.1%
To capture specific species	28.8%
Beginning of the activity in Nerbioi Median (IQR)	
Outer estuary	1995 (IQR 1986-2006)
Inner estuary	2001 (IQR 1990-2009)
Travel cost	
ME year ⁻¹	1.12
In which parts of the estuary do you fish?	
Outer estuary	87.0%
Inner estuary	53.4%
Perceptions of changes in water quality	
Better	80.1%
Equal	7.5%
Worse	4.1%
NA	8.2%

More details can be found in Pouso et al. (2018b).

quality (Pouso et al., 2018a, 2019b). However, the high percentage of locals among users, who do not have to invest great time or money to reach the recreational places, resulted in a relatively low monetary value per visit, compared to similar case studies in the literature (Ariza et al., 2012; Alves et al., 2017). The low monetary value per single visit was partially compensated by the many visits along the year. Also, the high representation of locals among users revealed the importance that marine spaces such as the Nerbioi estuary, located in highly urbanized areas, can have for many people. Restored blue spaces in urban areas, such as marine ecosystems, might have a lower environmental value than better conserved areas (e.g., protected coastal areas); still, they play a fundamental role by providing recreational opportunities and cultural ecosystem services to people living nearby (Jacobs et al., 2015; Bowen et al., 2019; Vert et al., 2019).

Beyond the monetary valuation, the questionnaires can be used to explore the social values that people attribute to cultural ecosystem services. In the Nerbioi estuary, the analysis of social values revealed that recreational activities matter to people for many reasons (e.g., “expending time with family

TABLE 4 | Summary of the main characteristics and results of the questionnaires distributed among beach goers in the Nerbioi estuary.

Beach recreation	
Distribution Details	
<i>n</i>	425
Distribution	July–August 2016
Socioeconomic characteristics	
Age	
<i>Mean ± SD</i>	42 ± 16
Gender	
<i>Women</i>	74.4%
<i>Men</i>	25.6%
Main motivations to practice the recreational activity (3 main motives)	
Sunbathing	86.2%
Relaxing and resting	72.8%
Bathing and cooling down	63.8%
Importance of the possibility of practicing aquatic activities to choose the beach	
Essential	25.6%
Important	50.4%
Low	17.2%
None	4.7%
NA	2.1%
Why did you choose this recreational spot today? (3 main reasons)	
Proximity to home	81.9%
Accessibility	34.3%
Tranquility	31.0%
Did you come alone?	
Yes	27.0%
No	72.1%
NA	0.9%
Visitors who practice aquatic activities in this beach	
Areeta	44.0%
Ereaga	65.0%
Arrigunaga	75.8%
Beginning of the activity in Nerbioi	
<1 year	10.1%
1–5 years	22.3%
>5 years	66.7%
NR	0.9%
Travel cost	
ME year ⁻¹	3.53
Perceptions of changes in water quality (only visitors with > 5 years coming to Nerbioi beaches)	
Better	82.7%
Equal	8.5%
Worse	6.0%
NA	2.8%

More details can be found in Pouso et al. (2018c).

and friend” “relaxation,” etc.), which are difficult to value in monetary terms. People value the relation with nature and with other people that the recreational activity facilitates; and this is linked to the relational values of ecosystem services (Chan et al., 2016). Also, spending time and practicing outdoor recreational activities in marine spaces, such as the Nerbioi

estuary, can have positive outcomes for human health (Borja et al., 2020). The analysis of social perceptions and behavior provide information on relational values that are so important for understanding cultural ecosystem services. In cultural ecosystem services research, presenting the instrumental values (monetary value) simultaneously with relational values helps to better understand how nature matters to people.

Once the whole process of restoration, including changes in human well-being, is understood, it is possible to link the social and environmental aspects influencing the ecosystem services and human benefits, through cause-effect relationships. These relationships can be used to build social-ecological models, e.g., using system dynamics model tools (Pouso et al., 2019a), which are able to simulate consequences for the human benefits (e.g., recreational activities) under future conditions. Furthermore, these models help to measure the resilience of the system to future pressures and/or impacts, which can be related to the status of regulating services of the restored ecosystem.

The consideration of the three value domains for analyzing the supply and demand sides of the ecosystem services allows us to build a more complete picture of the biophysical and social changes that shaped the present conditions in a restored ecosystem. In the case of the Nerbioi estuary, it has been shown how analyzing all these aspects allowed a deeper understanding of the system's dynamics. For example, analyzing exclusively the biophysical conditions would have led to the conclusion that conditions for recreational fishing were much better in the outer estuary, and that the activity will be concentrated there. However, analyzing the changes in accessibility with orthophotos and users' perceptions with face-to-face questionnaires, we were able to detect a problem for recreational fishers to access certain parts of the outer estuary. The decrease in accessibility to the left bank in the outer estuary could be a reason, together with the general improvement in biophysical conditions (more visible in the inner part), for the extension of the activity to the inner estuary. Our results suggest that the extension of the recreational fishing activity is a consequence of changes in users' perception on water quality and the availability of new areas (e.g., recreational port in the right side of the outer estuary), in the absence of any conscious measure adopted by authorities to mitigate the loss of recreational fishing opportunities after the extension of the industrial port facilities on the left bank. Another example of the added value of performing an integrated valuation to analyze changes in ecosystem services is related with cognitive processes. For recreational fishing, while fishers reported a decrease in fish abundance, environmental data suggested the opposite, with an increasing trend for the last 25 years (Pouso et al., 2018b). For beach recreation, although microbial pollution has decreased and most of beach goers perceived the water quality improvement, an important percentage of users still do not bathe due to the water quality, probably linked to the memory of past water pollution (Pouso et al., 2018c). The dual study of biophysical characteristics and users' perceptions and behaviors allowed us to find mismatches, which can be useful information for local managers.

The understanding of ecosystems as social-ecological systems, and the growing interest in approaches that consider ecosystem

services, makes inevitable the need to adapt the ways in which we evaluate restoration projects. This means changing the traditional evaluation processes, which have focused on changes in environmental conditions (Elliott et al., 2007), to integrated valuation processes that analyze the interdisciplinary outcomes of restoration actions. Furthermore, the declaration of the Decade on Ecosystem Restoration (2021–2030) by the United Nations, can be very important for coastal systems (Waltham et al., 2020), as a way to promote their restoration and gain, through new practical examples, their importance for recovery of both environmental conditions and ecosystem services.

In this context, the approach followed here can help to standardize the integrative analysis of ecosystem services in restored ecosystems, i.e., accounting for environmental, social and economic factors that shape the recreational activities and consequent human well-being, building one upon the other. Also, to comprehend the importance that each element has to the delivery of ecosystem services and the consequent human benefits.

CONCLUSION

In this article we present a framework for a standardized-integrative analysis of ecosystem services and consequent human well-being in restored marine ecosystems. Its theoretical background, based on marine management tools [DAPSI(W)R(M)], social-ecological system approach and following an integrative assessment of ecosystem services, provides a sound basis for the study of changes in cultural ecosystem services and human well-being in restored systems. Furthermore, it can be a useful approach when valuing the consequences of marine restoration projects, as it provides a systematic framework for the analysis of environmental, social and economic consequences of the restoration actions. Hence, these three domains transcend each other to give a new holistic view, which is different from what one would expect from the addition of the three domains, providing better and complete view of the restoration efforts.

DATA AVAILABILITY STATEMENT

All the information and data are available in the article of the authors cited in the text.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants, in accordance with the local legislation and institutional requirements.

AUTHOR CONTRIBUTIONS

SP, ÁB, and MU developed the idea of the manuscript. SP wrote the first draft. Each author contributed equally to the discussion

and in writing the final manuscript. All authors contributed to the article and approved the submitted version.

FUNDING

This work was supported by the Basque Water Agency (URA) through a convention with AZTI, and the MARS project (Managing Aquatic Ecosystems and Water Resources Under Multiple Stress) funded under the 7th EU Framework Program, Theme 6 (Environment Including Climate Change), Contract No.: 603378 (<http://www.mars-project.eu>). SP was

supported by a predoctoral grant from AZTI Foundation and a postdoctoral grant from the Department of Education of the Basque Government (Program for the Specialization of Doctoral Researchers).

ACKNOWLEDGMENTS

Miren Onaindia, Ana Iglesias, and Erik Gomez-Baggethun provided useful comments that helped in the development of the manuscript. This is contribution number 989 from AZTI- BRTA (Marine Research Division).

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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