Vol. 62, p. 267-287, jul./dez. 2023. DOI: 10.5380/dma.v62i0.82424 e-ISSN 2176-9109

UFPR | DMA DESENVOLVIMENTO E MEIO AMBIENTE

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Economic valuation of selected coastal ecosystems based on key provisioning and regulation services of Jaguaruna (Brazil)

Avaliação econômica de ecossistemas costeiros selecionados baseada nos serviços ecossistêmicos-chave de abastecimento e regulação de Jaguaruna (Brasil)

Giuliana Andréia SFREDDO[1*], Juan Adolfo Chica RUIZ[2], Tatiana Silva da SILVA[1], Eduardo Guimarães BARBOZA[1]

[1] Universidade Federal do Rio Grande do Sul (UFRGS), Porto Alegre, RS, Brasil.

[2] Universidad de Cádiz (UCA), Cádiz, CA, Espanha.

[*] Contact email: giulianaasfreddo@gmail.com

Article received on August 13, 2021, final version accepted on February 3, 2023, published on September 6, 2023.

ABSTRACT: The search for sustainability can be understood as a trajectory towards the maintenance of ecosystem services, which includes ways of minimizing the risk of losing them due to some imminent coastal hazard. Thus, this study aimed to evaluate the state of key-ecosystem services of provisioning and regulation in the southern coast of the state of Santa Catarina in the face of coastal stressors. For the development of the research, eight types of ecosystems were identified and mapped, according to a key ecosystem service offered by each of them, and the four largest in area were selected to apply the environmental valuation methodologies. The methodologies used were the Avoided Costs Method (ACM) and the Replacement Cost Method (RCM). The ACM calculates the economic value of the benefits that an ecosystem provides that would not be available if it did not exist. In turn, the RCM is based on the replacement cost of a damaged asset. Valuation results for Agriculture and Cattle farming; Continental waters and Marine environment; and Afforestation were respectively 1.74; 2.86; 2.89 million of dollars per year, while results for Dunes, Beaches and Restingas were in the range of USD 3,120–6,240 ha^{-1} yr^{-1}. These values should be understood as approximations of the true economic dimension of the damages caused by the use of ecosystems, since they correspond to how much the environment is capable of monetarily returning to individuals. Furthermore, these values cannot be used to calculate fines in case of environmental degradation.

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Keywords: coastal risk; environmental valuation methods; avoided costs method; replacement cost method; economic assessment; economic losses.

RESUMO: A busca da sustentabilidade pode ser entendida como uma trajetória em direção à manutenção de serviços ecossistêmicos, o que inclui minimizar o risco de sua perda devido a algum perigo costeiro iminente. Assim, este estudo teve como objetivo avaliar o estado dos serviços ecossistêmicos-chave de abastecimento e regulação no litoral sul catarinense em face a estressores costeiros. Para o desenvolvimento da pesquisa, oito tipos de ecossistemas foram identificados e mapeados, de acordo com um serviço ecossistêmico-chave ofertado por cada um deles, e os quatro maiores em área foram selecionados para aplicar as metodologias de valoração ambiental. As metodologias utilizadas foram o Método dos Custos Evitados (MCE) e o Método do Custo de Reposição (MCR). O MCE calcula o valor econômico dos benefícios que um ecossistema oferece que não estariam disponíveis se ele não existisse. Por sua vez, o MCR é baseado no custo de reposição de um bem danificado. Resultados da avaliação para Sistemas agropecuários; Águas continentais e Meio marinho; e Sistemas de reflorestamento foram respectivamente 1,74; 2,86; 2,89 milhões de dólares por ano, enquanto para Dunas, Praias e Restingas, resultados variaram entre USD 3.120–6.240 ha^{-1} ano^{-1}. Esses valores devem ser entendidos como aproximações da verdadeira dimensão econômica dos danos causados pelo uso dos ecossistemas, uma vez que correspondem a quanto o meio ambiente é capaz de devolver monetariamente aos indivíduos. Além disso, esses valores não podem ser usados para calcular multas em caso de degradação ambiental.

Palavras-chave: risco costeiro; métodos de valoração ambiental; método de custos evitados; método de custo de reposição; avaliação econômica; perdas econômicas.

1. Introduction

The concept of risk is related to the probability of failure of a fortuitous event, whose occurrence does not depend on the wishes of the parts involved. The existence of risk is constituted only when there is a valuation of some good, material or immaterial, as there is no risk without the notion that something can be lost (Godard *et al*., 2002; Castro *et al*., 2005; Correa *et al*., 2009), in this case, provisioning and regulation key ecosystem services in the face of coastal stressors.

Furthermore, coastal risk can be understood, according to ANCORIM (2017), as the expectation of losses that a particular hazard of natural or human origin in a coastal zone and during a specific period could produce, e.g.: personal, material damage, economic losses, environmental degradation. The severity of these potential risks depends fundamentally on the level of vulnerability and exposure to danger, such as storms, waste spills, erosion, wave impacts, as well as the value of goods and interests that could be affected (Gornitz, 1991; IOC, 2009; Spalding *et al.*, 2014).

Consequently, risk assessment implies estimating the total losses, that is, people affected, deaths, and material damage to an event with a determined degree of danger (Correa *et al*., 2009). It is desirable for risk indicators to be ecosystem-based, which means having environmental systems as analysis units, understood as a set of ecological, economic, and social elements (Costanza *et al.,* 2014; Munns *et al.,* 2015).

In this sense, understanding the concept of ecosystem services (ES) is necessary for a holistic view of its importance (Liu *et al.,* 2010; Raffaelli

& Frid, 2010; Menzie *et al.,* 2012; Costanza, 2020) for the present study, since changes in ES generally affect human well-being and are followed by changes on safety, health, and social and cultural relations (MA, 2003). Considering the definition of the Millennium Assessment of the United Nations (MA, 2003), ES are defined as the benefits that society obtains from ecosystems, and are classified into four main categories: provisioning, regulation, cultural, and support.

Provisioning services refer to those products that are obtained directly from ecosystems, such as food, water, timber, fuel, fibers, and genetic resources. Regulation services do not depend on transformation processes, that is, they come from ecosystems, without the need for intervention. Examples of this category are air and water purification, maintenance of biogeochemical cycles, pollination, disease prevention, climate regulation, erosion control, biological control, and protection against storms (Gómez-Baggethun & De Groot, 2007; MA, 2003). They are vital to human beings and very prominent in coastal areas.

Despite their importance, ecosystem services provided by coastal systems are commonly undervalued in the decision-making process, which leads to the constant modification, exploitation, and indiscriminate degradation of these areas in favor of other more productive options for land and resource use, which yield higher and immediate profits (Emerton, 2003).

Therefore, one of the purposes of determining the preferences of individuals, when applying valuation methods, is to assess ecosystem services (UNEP, 2010). Considering the perception of individuals in monetary terms is a way of making such services comparable to other economic sectors when it comes to making decisions about the use of natural resources. If well evaluated, the total economic value of an ecosystem, considering its services, usually exceeds the economic gains of activities based on the degradation or conversion of the ecosystem (Emerton *et al*., 2002; Pagiola *et al*., 2005).

One way to group environmental valuation methods is classifying them into direct and indirect methods. For this study, only indirect methods are considered, which allow for use and non-use values to measure environmental damage without having to relate these parameters to the direct willingness to pay or receive from individuals. The choice of using indirect valuation methods was to allow replication, with the ease of carrying out analysis remotely, in an increasingly globalized world, where geotechnologies support indirectly methods.

In this perspective, the objective of the present work is to assess and evaluate the state of selected coastal ecosystem based on marketable and non-marketable key-services of provisioning and regulation of the Municipality of Jaguaruna, in the state of Santa Catarina. In southern Brazil, Jaguaruna exhibits diverse characteristics among the continental and maritime ecosystems that compose it and their exposure to active coastal processes are factors that contribute to the risk of losing important ecosystem services. Furthermore, this area is part of the *Área de Proteção Ambiental da Baleia Franca* (Southern Right Whale Environmental Protection Area) (APABF) and presented, over the years, an unplanned urban expansion, which contributes negatively to the preservation of this area. Thus, we consider that Jaguaruna has characteristics that reflect the common situation of other segments of the Brazilian coasts. Therefore, environmental valuation methods of Avoided Cost Method and Replacement Cost Method were used as tools for determining the monetary value of natural resources.

2. Study area

2.1. Environmental and socioeconomic aspects

The Municipality of Jaguaruna is located to the south of Santa Marta Cape, in the southeast of the state of Santa Catarina. Its orientation is essentially aligned with the NE-SW axis, and it has approximately 38 km of extension in its coastline, and is part of the Southern Right Whale Environmental Protection Area (Figure 1).

This entire coastline is exposed to factors that affect coastal dynamics, such as waves and winds of different orientations throughout the year, watercourses of varying magnitudes, and coastal drifting. Regarding the latter, the most noticeable are positioned to the north and south of the territorial limit, corresponding respectively to the Camacho Channel and the inlet of the Urussanga River. The smallest and most frequent streams that contribute to continental drainage are the washouts.

The climate corresponds to the Cfa type, according to the Köppen climate classification (Alvares *et al*., 2013), which is equivalent to a region of

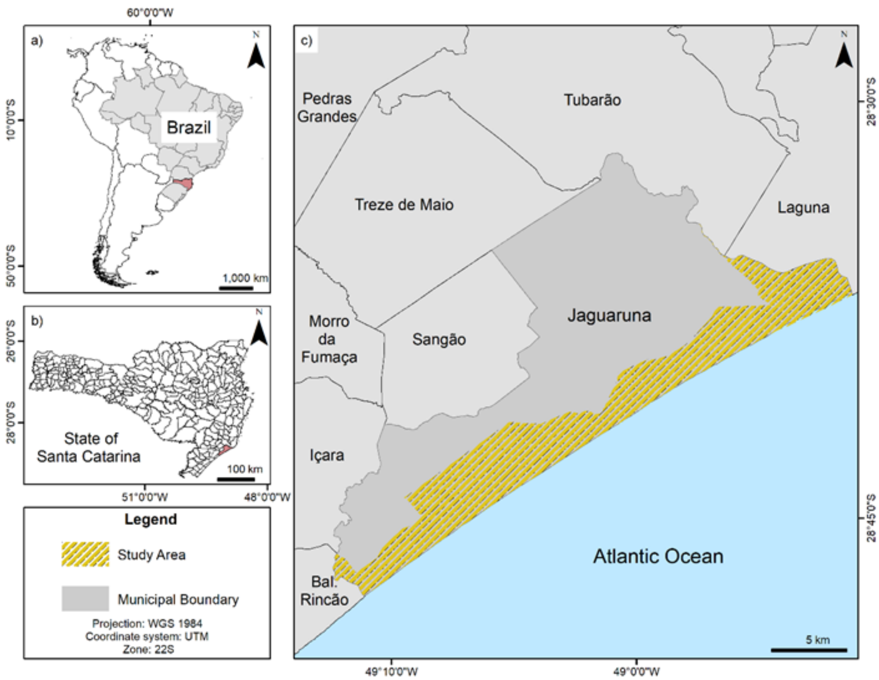

FIGURE 1 – Location of the Municipality of Jaguaruna (c), state of Santa Catarina (b), southern Brazil (a). The hatch area indicates the studied coastal segment.

warm temperate climate, without the presence of a dry season, and with hot summers. The monthly average temperature varies between 18º and 20ºC, with average annual rainfall between 1,460 to 1,820 mm, and with rains well distributed throughout the year (Climate Data, 2020).

Wave dynamic is controlled by the wind regime, which varies according to the time of year. Thus, in the period from October to March, the predominant wave direction is from the east quadrant, while between April and September the dominant waves are from the south quadrant (Araujo *et al*., 2003). Regarding astronomical tides, the regime is a mixed semi-daytime tide with approximately 0.6 m (Araujo *et al*., 2003). Also, the most significant tides are meteorological, with an amplitude of about 1 meter (Giannini, 1993).

Furthermore, the wave dynamics control the coastal drift, which varies according to the time of year. South of the Cape of Santa Marta, the maximum coastal drift to the north is observed in autumn, while wave conditions in spring with the predominance of east waves generate drift directed to the south, as well as in summer and winter, resulting in an annual drift predominant to the south (Siegle & Asp, 2007).

These coastal dynamics processes are capable of substantially modifying this geological unit, since it is a recent unit, having been formed during the Holocene. Its paleogeographic evolution was described by Vieira *et al*. (2009) through four evolutionary stages based on sea-level variations, from the lower Pleistocene regression (> 120 ka BP) to the beginning of the Holocene maximum regression (~ 5.4 ka BP). This model is correlated to that of Villwock & Tomazelli (1995), which describes the evolution of the coast of Rio Grande do Sul in lagoon-barrier systems.

Regarding population and economic aspects, Jaguaruna had an estimated population of 20,547 inhabitants in 2021 and a gross domestic product of approximately 105.92 million dollars in 2017 (IBGE, 2017; 2021). Also, according to official estimates, in 2017, agriculture and cattle farming moved around 19.17 million of dollars, industry 18.93 million of dollars, the service sector 46.49 million of dollars, and public administration expenses 21.33 million dollars. The average monthly wage of formal workers was two minimum wages that corresponded to 595 dollars in that year (IBGE, 2017).

2.2. The urban growth of Jaguaruna and the risk propensity

From the second half of the 1970s, there was an increase in the demarcation of subdivisions in the coastal zone of Jaguaruna, driven by a high demand for beach areas and tourism (Gruber *et al*., 2017a). This process followed the national trend that quickly transformed Brazil from a rural and agricultural country to an urban and metropolitan country (Martine & McGranahan, 2010), when the highest population density began to concentrate on the coast. Regarding the coast of Santa Catarina (SC), the results of the study of De Andrés *et al*. (2018) showed that 26% of urban occupation in the state of SC is located on the coast, which represents approximately 2% of the state's area.

From the 1980s onwards, there was significant growth in the occupation of coastal lands with insufficient territorial planning, flawed legislation, and deficient inspection by the government, which caused significant changes in environmental systems and, consequently, a tendency to higher exposure to risk.

In 2010, the diagnosis "Coastal Economic Ecological Zoning of the Coastal Management Plan" classified the coastal region of Jaguaruna as a Priority Preservation Zone, except for consolidated urban settlements and few areas destined for urban expansion (Gruber *et al.*, 2017a). With this perspective in mind, and considering the conflicts of use regarding ecosystem services, in 2011, the Federal Public Ministry filed a public civil action against the Union, which led to the embargo of new buildings in the areas adjacent to the beaches.

This new legal situation stopped real estate projects and enterprises that would potentially reproduce an unsustainable development matrix, but left the entrepreneur and the municipal public power without alternatives (Martins, 2017). The municipal tax receipt has declined due to the tourism collapse and the occupation of irregular and illegal areas, which made it impossible to collect the Land and Urban Property Tax.

Other problems that the municipality has been experiencing since then include the occupation of environments protected by current legislation; construction and trade of irregular properties; landscape changes; degradation of archaeological sites; low transfer of funds for municipal environmental management (Martins, 2014; Cristiano *et al.*, 2015; Gruber *et al.*, 2017a; Martins, 2017); modification and deterioration of ES; and conflicts of use between ES. All of these factors lead the municipality to present a high risk of environmental and economic losses.

3. Materials and methods

3.1. Definition of ecosystems and their key provisioning and regulation services

This methodology considers as a fundamental starting point a definition of an ecosystem, proposed by Odum (1953), Odum & Barret (2015), which considers the ecosystem as the basic functional unit of an area, since it considers the interaction between the totality of organisms and the abiotic environment, each influencing the properties of the other, and this relationship being necessary for the maintenance of life as it exists on Earth.

As an extension of this definition, we have the benefits provided by ecosystems, which are called Ecosystem Services (ES). ES include provisioning, regulating, support and cultural services. MA (2003) conceptualizes Provisioning Services as products obtained directly from ecosystems, such as fresh water, biomass production, fiber, wood, capture fisheries; and Regulation Services as benefits obtained from the regulation of ecosystem processes, such as pollination, pest regulation, water purification, hazard regulation, sediment balance, etc.

Changes in ES offered by ecosystems can be alerted by indicators that measure environmental risk, which, in turn, originate from environmental changes, such as ecosystem loss due to the progression of sand over the continental area. Indicators are defined by the *Ministério do Meio Ambiente* (Brazilian Ministry for the Environment) as quantified information of a scientific nature, easy to understand, used in decision-making processes at all levels of society, being useful as evaluation tools for certain phenomena (MMA, 2019).

This study focuses on key ecosystem services for provisioning (ESp) and regulation (ESr), as we understand that they are the main services affected by the risks to which coastal ecosystems are exposed in the segment analyzed in Jaguaruna, which encompasses the entire Southern Right Whale Environmental Protection Area (APABF).

The work of Barbier *et al.* (2011), Scherer & Asmus (2016), Asmus *et al.* (2018), and Silveira (2019) were used in the identification of ecosystem services, meaning that only key-ES were considered, following the concept adopted by Barbier *et al.* (2011) and described by Silveira (2019). Key-ES represents the most relevant service for the functioning of a certain activity in a portion of the territory (Silveira, 2019), in this case the ecosystems under indicative of risk. Meanwhile, the main risks to which these ecosystems are submitted were pointed out in an expert consultation workshop, starting from the study by Barbier *et al.* (2011) who mapped the main risks to which ecosystems are subjected as "human drivers of ecosystem change". Hence, to carry out the mapping of land use, it was considered to group ecosystems according to the similarity between the provisioning and regulation services provided by them.

3.2. Data structuring

Ecosystems based on their provisioning and regulation services were mapped through manual vectorization directly in ArcGIS, through photointerpretation, using the Basemap provided by the software itself as a database. First, the ESp and ESr provided by each class of ecosystems considered were identified, as well as the indicators of risks to which they are subjected.

Agriculture and cattle farming systems were identified based on large properties, in shades of green and yellow, characteristic of pastures for livestock. Inland and marine waters were determined by their dark blue color, smooth to slightly granular texture, well-defined edges, and contrast with adjacent areas. PMAP-SC reports (2018; 2019) helped define fishing areas. Dunes, beaches, and restingas were defined by the direction of the sedimentary input, by their light-yellow color, and by where the vegetation is sparse due to the migration of the dunes. Forests correspond to places where the vegetation was dispersed, in the form of patches that did not follow any geometric pattern. In contrast, Afforestation showed a well-defined planting pattern, large extensions, characterized by geometric shapes with defined edges and dark green color, being characteristic of Pinus. Rangelands and wetlands were determined by their dark color, granular texture, and proximity to low relief areas. Finally, urban systems were mapped through streets, blocks, and construction pattern. To validate the result, a comparison was made with the data provided by Mapbiomas (Mapbiomas Project, 2020).

To proceed with the environmental valuation methodology, the largest systems in the study area were chosen:

i) agriculture and cattle farming;

ii) continental waters and marine environment (analyzed together);

iii) dunes, beaches, and restingas; and

iv) afforestation. The key-ES identified for each ecosystem was described for each of the previous classes. Table 1 presents the synthesis of the data used for this study.

3.3. Environmental valuation

The conversion from the Brazilian real (BRL) to the United States dollar (USD) was determined by the authors based on the quotation corresponding to January 15th 2020, to avoid the impacts on prices, due to the Covid-19 crisis and considering the most recent data obtained for the study. Thus, 1 BRL = 0.239 USD (Exchange Rates UK, 2020).

3.3.1. Avoided costs method

The Avoided Costs Method (ACM) calculates the economic value of the benefits provided by an ecosystem that would not be available if such an ecosystem is removed. Therefore, this economic value would represent an additional cost for society

TABLE 1 – Ecosystem data framework with risk indicators, method summary and data source. Where ES is Ecosystem Service, ACM is Avoided Costs Method and RCM is Replacement Cost Method.

Ecosystem	Key-ES affected	Risk indicators	Environmental valuation method	Method summary	Data source
Agriculture and Cattle farming	Livestock production	Loss of the entire system due to sand progression over the continental area; Damage to cultivated species; Damage to cattle.	ACM	Monetary value in SC of an adult cattle per km²; Average production value (weighted average).	(CPEA, 2020; Cezar *et al*., 2005).
Continental waters and Marine environment	Fisheries capture	Damage to individuals; Collapse of fish stocks; Water pollution.	ACM	Total monetary value of fisheries captures in Jaguaruna per year.	(CEAGESP, 2020; PMAP-SC, 2018; 2019).
Dunes, Beaches, and Restingas	Hazard regulation	Increased erosive power and loss of sediment to the ocean in the event of a storm; Erosion due to climate change or extreme event; Increase in buildings such as defenses or tourist infrastructure.	RCM	Beach nourishment by section. Multiplying the section by the length of the coastline. Multiplying the total amount of sand required by the m³ of sand.	(SMI, 2020).
Afforestation	Production of wood as socioeconomic resource	Loss of soil quality; Loss of biodiversity; Soil erosion.	RCM	Monetary value in SC of Pinus per km² per year.	(Shimizu, 2008).

if that environmental service were to no longer be available.

The implicit idea of ACM is that the funds spent on substitute or complementary products for some environmental characteristics can be used as an approximation to monetarily calculate the "perception of individuals" regarding changes in ecosystems. These are expenses for the defense or prevention of environmental characteristics for the protection of populations (Pearce, 1993). ACM was used to monetarily estimate the value of the Agriculture and Cattle farming; and Continental waters and the Marine environment classes provide for the population.

In the first case, the calculation aimed to determine the price of livestock production through the adult cattle per km² for the state of Santa Catarina. The definition of adult cattle considers that the animal went through the complete cycle, which consists of breeding, reproducing, and fattening. The production period of 24 months was considered as the average time for slaughter. For the Santa Catarina micro-region, the average head of cattle per hectare is 0.55, and one animal unit (AU) is equivalent to an average of 468 kg (Cezar *et al*., 2005).

Furthermore, the historical price series from 1997 to 2019 of the adult cattle arroba was considered (1 arroba equals to 14.668 kg), according to CEPEA (2020), to obtain a value without the influence of market fluctuations.

For the Continental waters and Marine environment class, the calculation of the gross product of the annual fish biomass production was carried out based on the data collected in the technical reports of the *Projeto de Monitoramento da Atividade Pesqueira no estado de Santa Catarina* (Monitoring Project of Fishing Activities in the state of Santa Catarina). The data selected for the study refer only to those collected by the PMAP in Jaguaruna in the period that covered from July to December 2018 and from January to June 2019, totaling one year of data (PMAP-SC, 2018; 2019).

The market value for each of the species documented in the reports was determined by the authors, according to the average price of the *Companhia de Entrepostos e Armazéns Gerais de São Paulo* (São Paulo Terminal Warehouse) (CEAGESP) corresponding to January 2020. To obtain the total gross annual value, it was considered that the category defined by PMAP-SC (2018; 2019) as "Other species" has price's average of the all categories of species caught, except for shrimps. Shrimps are valued separately, and considers the price's average of the different species of shrimps sold at CEAGESP (2020).

3.3.2. Replacement cost method

The Replacement Cost Method (RCM) is based on the cost of replacing or restoring a damaged good, and this cost is understood as a measurement of its benefit (Pearce, 1993). In this sense, replacement costs indicate that there will be greater benefits to society with its implementation than otherwise. In addition, this approach is necessary for situations where the repair of the damage is essential due to some environmental restriction.

The risks for this procedure, according to Pearce (1993), are related to the perception by a part of society that the costs are negligible when compared to the number of benefits obtained by the recovery of a given ecosystem. The method works by adding the costs of repairing the negative effects, which are a consequence of some disturbance in environmental quality. The RCM was used for the classes of Dunes, Beaches and Restingas, and Afforestation Systems, to estimate their values, assuming that the cost of recovering each of these systems represents the total value of the environment and the corresponding key-ES.

To determine the final monetary value of Dunes, Beaches and Restingas, a simplification of the beach nourishment calculation was used, according to Barletta *et al.* (2008). For this purpose, the current beach profile with linear approximation was plotted, considering the slope angle of 2 degrees, characteristic of a beach with a dissipative domain. Afterward, Dean's stability profile (Dean, 1977) was plotted, according to Equation 1.

$$h(y) = Ay^{\frac{2}{3}} \tag{1}$$

In which, h is the water depth as a function of the distance from the coast y, and A is the parameter that depends on the granulometry of the sediment. A 0.103 mm granulometry was used, based on the work of Gruber *et al.* (2017b).

Then, the closing depth for the Jaguaruna beach was calculated, according to the Hallermeier equation (Equation 2) for a wave with a significant height of 1.98 m and a duration of 8 s (Contestabile *et al*., 2015).

$$h_c \cong 2,28H_s - 68,5\left(\frac{H_s^2}{gT^2}\right) \tag{2}$$

Where, h_c is the closing depth, H_s is the significant wave height, g is the acceleration of gravity and T is the associated wave period. The closing depth hc returned the value of 4.09 m. With the script building on the MATLAB software, the integral of the profile to be nourished in one meter of beach extension was calculated. Also, the value assigned to each cubic meter of sand was USD 9.68, based on the nearest and most recent beach nourishment in Canasvieiras between the end of 2019 and the beginning of 2020 (SMI, 2020).

In the case of Afforestation systems, the calculation of the environmental valuation was carried out based on the profitability of the Pinus for the southern region of Brazil. The choice for this species is that due to its characteristics of rapid growth and wood quality, it is the most planted and used industrially in the southern region of Brazil, and it is seen as a sustaining species of an important production chain (Shimizu, 2008; Camargo & Matos, 2016). The database was obtained from Shimizu (2008), which simulated 10 years, between 2008 and 2017.

4. Results and discussion

4.1. Mapping of ecosystems based on key ecosystem service

The ecosystem map based on Key Ecosystem Service resulted in eight classes:

i) agriculture and cattle farming;
ii) continental waters;
iii) dunes, beaches, and restingas;
iv) forests;
v) afforestation;
vi) rangelands and wetlands;
vii) marine environment; and,

viii) urban systems areas, according to Figure 2. Table 2 shows the total area of each class. The widest class is Dunes, Beaches and Restingas with 3,200 ha, which corresponds to 29% of the study's area; and the Rangeland and Wetland is the smallest class, with only 200 ha, or 2% of the total area.

The concept of Key Ecosystem Services was used by Barbier *et al.* (2011) in their review on the value of estuarine and coastal ecosystem services, and later by Silveira (2019) in his work in southern Brazil on proposal of a systemic analytical framework to support environmental planning and management. Its concept aims to facilitate the territorial planning process according to the ecosystem logic (Silveira, 2019).

In the case of coastal ecosystems, studies indicate that around 60% of them have already been degraded on a worldwide scale, and this is a progressing trend, as a consequence of land use changes, alteration of biogeochemical cycles, destruction and fragmentation of natural habitats, introduction of species, and changes in climatic conditions (changes in rainfall, storm patterns, extreme temperatures) (Barbier *et al*., 2011; Barragán Muñoz & Chica Ruiz, 2013; Brenner *et al*., 2010; De Groot *et al*., 2010). Such changes are intrinsically linked to ecosystem services. Generally, these services are

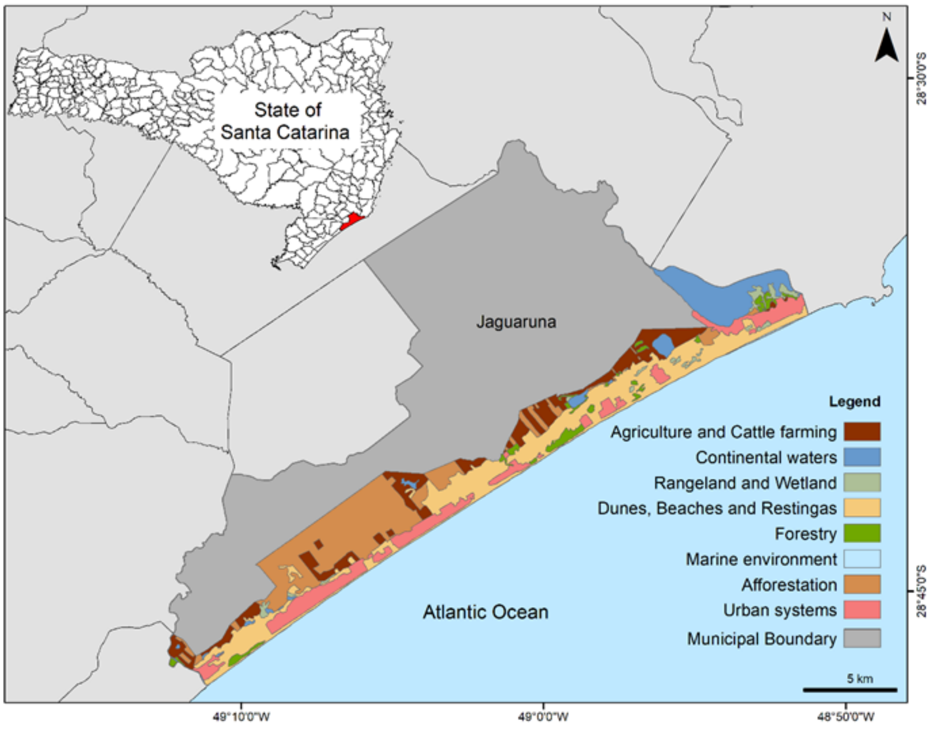

FIGURE 2 – Land use map of the coastal area based on Key Ecosystem Service in the Municipality of Jaguaruna – SC (state of Santa Catarina). Eight classes were identified and five of them were selected for the application of environmental valuation methods.

invisible to humans and, therefore, are not perceived and / nor valued. Furthermore, it must be considered that when damaged, losses can be significant and difficult to recover.

TABLE 2 – Land use area based on Key Ecosystem Service in the Municipality of Jaguaruna – SC.

Class	Area (ha)	Area (%)
Agriculture and Cattle farming	1,600	14
Continental waters	1,300	12
Rangeland and Wetland	200	2
Dunes, Beaches and Restingas	3,200	29
Forestry	400	4
Marine environment	-	-
Afforestation	2,800	25
Urban systems	1,500	14
Total	11,000	100

4.2. Environmental valuation

For the classes of Agriculture and Cattle farming; and Continental waters and Marine environment, the Avoided Costs Method (ACM) was chosen. While for the classes of Dunes, Beaches and Restingas; and Afforestation, the Replacement Cost Method (RCM) was used, as discussed below. In these methods, the value of an environmental resource, in this case the Key Ecosystem Service, is estimated through a production function, using as reference products on the market that are affected by the change in the provision of the environmental resource (Silva, 2008; Kay *et al.*, 2019).

Concerning the Agriculture and Cattle farming, these systems around the world feed the current population of more than 8 billion people worldwide, playing an important role in shaping the environment as well as the economy. While natural ecosystems are sources of numerous wild foods and animals, the needs of the growing population will not be met without agriculture and cattle farming. Whereas, the most practiced economic activity in this sector selected for the study is livestock production. Then, the valuation for this class was based solely on adult cattle and its value was used to determine the market environmental valuation. Through an exponential curve adjustment, the value of R$ 160.00 BRL was obtained for the arroba of the adult cattle for January, 15th 2020, which corresponded to 38.32 dollars on that day.

The calculation resulted in gross production of USD 1,088.69 ha^{-1} yr^{-1}. Considering that the mapped area corresponds to 1,600 ha, the resulting value for Jaguaruna is USD 1,741,902 dollars per year. In a study about farming production in conventional fields in Canterbury, New Zealand, Sandhu *et al.* (2008) estimated the mean value of the marketable ecosystem service "food" at USD 3,220 ha^{-1} yr^{-1}.This value is well above what we found for Jaguaruna, due to a series of factors, such as production costs and methods, that differ between countries. Even so, the market values represent the value of those ES which help in its production (Heal & Small, 2002).

For Continental waters and the Marine environment, the determination of the value of the environment was based on the total species captured in Jaguaruna (Table 3). The sector of fishing and aquaculture provides a significant contribution to food and nutrition security, supports the livelihoods of hundreds of millions of people around the world (FAO, 2021), and constitutes an important economic activity for Jaguaruna.

TABLE 3 – Gross annual value in millions of artisanal fisheries in Jaguaruna, based on the total catch by species (PMAP-SC, 2019) and value by species (CEAGESP, 2020). PMAP-SC refers to Monitoring Project of Fishing Activities in the state of Santa Catarina and CEAGESP to São Paulo Terminal Warehouse. Prices correspond to January 2020.

Species	Value ($/ kg)	Production (t)		Total weight (t)	Annual Value by Species in Thousands of Dollars ($)	Gross Annual Value in Millions of Dollars ($)
		Jun - Dec (2018)	Jan - Jun (2019)			
Mullet fish	1.677	139.850	348.940	488.790	819.700	2,864,668
Corvina	1.198	123.070	29.750	152.820	183.078	
Kingcroaker	0.839	82.510	29.140	111.650	93.674	
Shrimp	5.991	53.840	73.920	127.760	765.410	
Bluefish	2.876	37.470	0	37.470	107.764	
Flounder	2.876	0	51.250	51.250	147.395	
Callinectes	1.677	113.070	167	280.070	469.677	
“Others”	2.448	82.540	31.010	113.550	277.970	

Considering that the waters occupy volume for the production of fish (and not the area, as in the other classes), the results pointed out a total gross value, in this case, of USD 2,864,668 per year. Other studies evaluated fish production per hectare year or meter year, which makes it difficult to draw a parallel between them. In this sense, we highlight the studies of McArthur & Boland (2006) in the southern of Australia that who valued fish, shrimp, and crab production at this site at USD 1,436 ha^{-1} $yr^{-1,}$ and more recently Sangha *et al.* (2019) who assessed the status of ecosystem services through Commercial fishing & Aquaculture in the Northern Territory of Australia at USD 179.60 m^{-1} yr^{-1}.

Regarding Dunes, Beaches, and Restingas, the extensive degradation induced from coastal development, reduced sediment delivery from major rivers, increased coastal erosion and relative sea-level rise (MA, 2003; Syvitski *et al.*, 2005) indicate a continuing negative trajectory for coastal ecosystems and their services around the world.

From this point, the calculation of value was based first on the amount of sand that would have to be replaced on a section of beach, which resulted in 75.46 m² of sand, according to Figure 3. Considering that each cubic meter of sand costs USD 9.68, the total value of nourishment for one meter of beach extension was USD 730.45. Therefore, the average value per hectare of surface resulted in USD 62,420.95 ha^{-1}.

Although is the ecosystem with the largest covered area and high total value attached to the system in Jaguaruna, it is necessary to understand that the high value found is not related to the cost in just one year. Durability of beach nourishment is an important issue for environmental valuation, and plans generally estimates of protection about 10–20 years (Finkl & Walker, 2002). Thus, the range of value of this ecosystem with its services can be estimated in a range of USD 3,121.05–6,242.10 ha^{-1} yr^{-1}, which corresponds to a total value for the 38 km of coastline in Jaguaruna in the range of USD 13,876,618.88–27,752,23.76 per year.

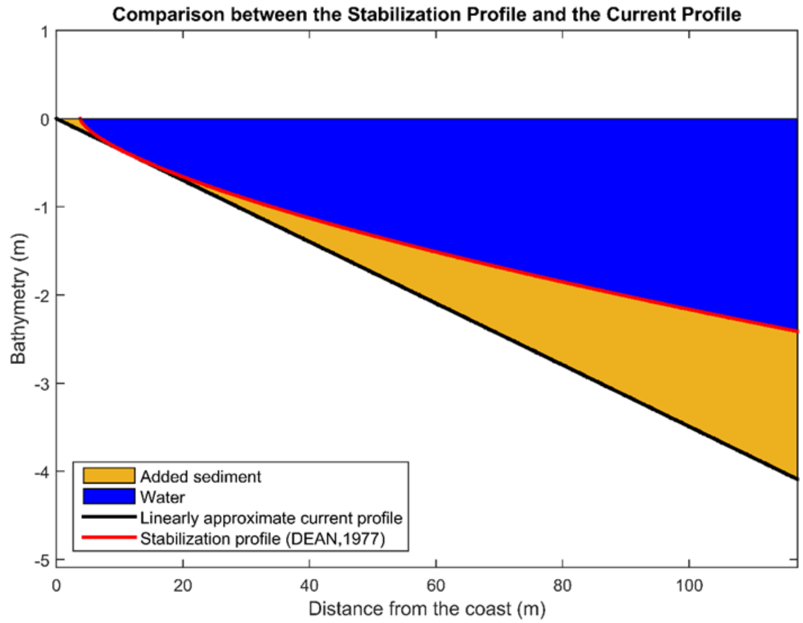

FIGURE 3 – Current coastal profile of Jaguaruna, linearly approximated, in black, and the stabilization profile, using Dean's equation (1977), in red. The area hatched in yellow represents the integral of the profile to be nourished, which equals 75.46 m² of sand for each meter of coastline.

In 2001, Sathirathai & Barbier estimated the value of USD 3,679 ha^{-1} yr^{-1} for the replacement cost of using an artificial barrier for erosion control in Thailand (Sathirathai & Barbier, 2001), which in current values, corrected for inflation, would be a total of around USD 5,100 ha^{-1} yr^{-1}. Another way of valuing services offered by these kinds of systems is the willingness-to-pay methodology. Landry & Liu (2009) analyzed the valuation of services offered by beaches in North Carolina (USA) using this method for an increase in beach width of 100 feet and obtained, as a result, the value of USD 166/trip or USD 1,574 per visiting household per year.

From these results, two main points become clear: the control of hazards offered by Beaches, Dunes and Restingas is undoubtedly one of the most valuable ES in terms of market and non-market value, as protection provided by coastal ecosystems, especially in the face of extreme storms, tsunamis and sea level rise; there are still few studies that value Beaches, Dunes and Restingas ecosystems by their replacement cost, but based on these few studies, the replacement cost is considerably larger than the individual's perceived value measured by the willing-to-pay methodology.

In the case of Afforestation, this class draws our attention, as it is even larger in area than Agriculture and Cattle farming, comprising 25% of the study area. This result showed the importance of this activity in the region. Although many studies showed that, due to their high adaptive capacity and rapid growth, species of Pinus are one of the main exotic invaders on the globe, and afforestation impacts are many worldwide, this activity has an outstanding economic role in the coastal areas of Brazil (Bechara, 2003; Shimizu, 2008; Camargo & Matos, 2016).

From that, the calculation considered the net value of Pinus of USD 1,032.83 ha^{-1} yr^{-1}, as well as the area of 2,800 hectares. Thus, the value of this environment is estimated at USD 2,891,924 per year. Ninan & Inoue (2013) compiled in their study the valuation of forest systems in different parts of the world, which showed wide variation between forest sites, regions and countries, ranging from USD 8 ha^{-1} (Iran) to USD 4,080 ha^{-1} (Japan). Moreover, Fiorini *et al.* (2020) evaluated the payment for ecosystem services on a forest cover in Rio de Janeiro and the results pointed to a value of restoration for the ecosystem ranging from USD 150–1,405 ha^{-1}. Nevertheless, the value per hectare found for Jaguaruna is close to the one estimated by Fiorini *et al*. (2020) and by Costanza *et al*. (1998), which estimated the value of ecosystem services assessed for whole global forests at an average of USD 1,430 ha^{-1}.

The economic valuation of coastal and marine resources being ignored is an issue recognized worldwide, at local, regional or national scales (MA, 2005; IPBES, 2022) and it is no different in Brazil. Among key ES selected, the economic impact and value of providing services added up to a total of USD 7,498,494 yr^{-1} and the value of regulating service range between USD 13,876,618.88–27,752,23.76 yr^{-1}. These values are particularly high if we consider that the gross domestic product was of approximately 105.92 million of dollars in 2017. Thus, only five ecosystems with their key services already account for almost 20% of all municipal revenue. In addition, these resources support many sustainable and unique resources and generate local jobs.

By evaluating the monetary values of coastal and marine resources for Jaguaruna (SC), this study opens space to bring this discussion to the fore in the development of policies for the maintenance of the ecosystem and its services. During the time this article was under elaboration, the first law in Brazil on payment for environmental services was passed, Law No. 14,119, of January 13, 2021 (Brasil, 2021). Under this law, payments for environmental services can be made, in accordance with the legislation, as direct, monetary or non-monetary payments, among other forms. In addition, the Law seeks mainly to encourage the conservation of ecosystems, water resources, soil, biodiversity, genetic heritage and associated traditional knowledge.

In summary, in order to develop Jaguaruna and the other coastal areas of Brazil as a whole and bring humans closer to the ecosystem, the authors propose that existing opportunities based on nature be developed and expanded, adapted to the reality of each location, such as recreational fishing, artisanal fishing, water sports, kitesurfing, windsurf, ecological trails, etc. These activities must be carried out by applying equitable benefit sharing principles and appropriate governance mechanisms to achieve more sustainable development.

4.3. Limitations

It is important to highlight that, to make this study possible, assumptions and simplifications were made according to the reality of the available data. Firstly, it was diagnosed in field visits that agricultural activities coincide in area with extensive livestock production, and that fishing activity compiled by PMAP-SC (2018; 2019) occurs in Continental waters and the Marine environment. In addition, for Afforestation, only the value of the genus of Pinus species was considered, which are the most commonly planted in the region. Finally, in Dunes, Beaches and Restingas. there were mathematical simplifications made to obtain the beach profile.

It is important to note that the methods used so far are indirect. Thus, the values must be understood as approximations of the true economic dimension of the damage caused by use of the ecosystems and must be used when direct methods cannot be applied due to lack of data (ABNT, 2005). However, it is understood that this valuation is relevant as a tool for measuring environmental risks and that a monetized approach to ecosystem services is more easily integrated into the agenda of decision-makers.

Furthermore, it should also be noted that to obtain these values, normal situations of operations and/or production were considered and that there are climatic, commercial, and administrative factors that can interfere in the result. Some examples of the factors that can interfere are the excess or lack of rain for long periods; climate changes; commercial agreements or embargos on products, changes in the taxation of activities carried out, among others.

5. Conclusions

This study assessed the state of selected coastal ecosystems based on key provisioning and regulation services in the Southern coast of Santa Catarina State. Although there are not many studies of this type performed in Brazil, the results found are compatible with studies conducted in other parts of the world.

Environmental valuation methodologies are important to estimate the value of a given ecosystem and their ecosystem services (ES), and to enable human beings to have a more concrete view of their existence. Considering the history of degradation of ecosystems and their ES in the world, this approach is useful to improve their conservation and supporting decision-makers to better manage and plan, designing better policies.

It is worth mentioning that these values correspond to how much the environment is capable of offering monetary returns to individuals, and not just a value that can be applied for calculating fines, in the case of environmental degradation. On the other hand, the results of the study can be used in awareness campaigns, to exemplify to the population the annual value that we would have to recover a degraded ecosystem, and, consequently, its ES.

It is necessary to be aware of the importance of maintaining the flow of services of each ecosystem, to allow functions and processes to be continued and develop naturally. In this perspective, the valuation of these ecosystems and their services makes it possible to prioritize, from a financial point of view, those that need management strategies the most.

Continued monitoring of this area is of great importance when it comes to sustainably managing these coastal ecosystems and their uses and activities, given the presence of the Southern Right Whale Environmental Protection Area in this municipality. Besides, it is necessary to give importance to the touristic activity of this area, which depends directly on its good state of conservation and management.

For future studies, further advances in environmental valuation models must include potential accidents or environmental disasters, as well as with far-reaching data, collected directly in the field. Studies with direct methods of evaluation, which consider the individual's perception of the value of the environment, would also bring valuable elements to better understand and define the value of ecosystem services in this region.

Funding

This research was funded by the "Asociación Universitaria Iberoamericana de Postgrado (AUIP), Programa de Movilidad Académica entre Universidades Andaluzas e Iberoamericanas asociadas a la AUIP, Julio de 2019" and the "Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), grant number 141344/2017-2".

Acknowledgments

The authors would like to thank the research funding agencies, AUIP and CNPq, for the funding received, and the Department of History, Geography and Philosophy of the University of Cádiz for welcoming the authors of this study.

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