Ocean and Coastal Management 218 (2022) 106034

Contents lists available at ScienceDirect

Ocean and Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

The economic impact of sea level rise-induced decrease in the carrying capacity of Catalan beaches (NW Mediterranean, Spain)

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ARTICLE INFO

Keywords:
Sea-level rise
Economy
Coastal tourism
Shoreline erosion
GDP
Input-output analysis

ABSTRACT

Sea-level rise (SLR)-induced erosion will contribute significantly to the reduction of the surface of beaches worldwide. In the absence of adaptation measures, this implies a decrease in the recreational carrying capacity provided by beaches, which in turn could significantly affect the economies of the areas associated with the "sun-and-beach" tourism model. Here, we propose a methodology to assess the demand-side economic impact by applying an input/output analysis, assuming that the beach carrying capacity is linked to the potential tourism demand, and consequently, to tourism consumption and output. Moreover, to properly evaluate the spatial variations in the impact throughout the territory, the effects are downscaled to the county level using a set of location coefficients. The model is applied to Catalonia, one of the most visited coastal regions in the Mediterranean. Here tourism contributes approximately 11% of its gross domestic product (GDP) and most visitors are related to coastal tourism. Although SLR affects the entire region with relatively small spatial variations in the induced shoreline retreat, its impact on the beach carrying capacity per county and the number of potential users exhibits a large spatial variability. Considering the RCP8.5 scenario as a reference, Catalonia's key coastal tourism brands, Costa Brava and Costa Daurada, will be the most affected economically, with an expected GDP loss of approximately 2200 million € and 1820 million € (at 2019 values), respectively. Finally, these local estimations were used to identify where the greatest benefits/returns would be derived from implementing adaptation measures to the SLR. This analysis was done by normalising the GDP losses that could be avoided in each county, with the length of beaches needed to provide recreation services to sustain the tourism economy.

1. Introduction

According to the United Nations World Tourism Organization (UNWTO), the total economic contribution of tourism in 2019 was 10.3% of the global gross domestic product (GDP), generating one in 10 jobs worldwide (UNWTO, 2020). The Mediterranean region is the world's leading tourist destination, attracting approximately 30% of international tourism, with coastal destinations comprising half of the arrivals (Plan Bleu, 2016). Coastal tourism is the largest sector across the Blue Economy in the European Union in terms of global value added and employment (European Commission, 2021). The majority of coastal tourism is based on the sun-and-beach model, and as a consequence, this type of tourism accounts for a significant percentage of the national revenue in many coastal countries, with beaches as the primary natural resource providing economic and social values (e.g. Houston, 2018).

Coastal tourism is one of the most sensitive economic sectors to climate change (e.g. Jones and Phillips, 2018; Arabadzhyan et al., 2021), and this sensitivity may trigger a crisis in the tourism industry at many destinations. Furthermore, sea-level rise (SLR) and water scarcity have been identified as key factors that may affect coastal tourism in Mediterranean countries (Moreno and Amelung, 2009). Therefore, it is vital to understand the impacts and consequences of climate change for the sustainable development of this sector (De Sausmarez, 2007; Meheux and Parker, 2006) as well as to consider different adaptation measures (Moreno and Becken, 2009; Scott et al., 2012a). This is also extensible to other risk domains in the Mediterranean, where existing environmental problems are being exacerbated by accelerating climate change (Cramer et al., 2018).

Within the Mediterranean, Spain is a traditional sun-and-beach destination in which the coastal areas have experienced intense urban sprawl and tourist development. Approximately 12% of the national economy comes from tourism (INE, 2019). Particularly, Catalonia

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https://doi.org/10.1016/j.ocecoaman.2022.106034
Received 23 July 2021; Received in revised form 30 December 2021; Accepted 3 January 2022
Available online 13 January 2022

received approximately 23% of the foreign tourists visiting Spain in 2019 (INE, 2019), making it one of the most visited coastal destinations in the Mediterranean (European Commission, 2021). Excluding Barcelona, which encompasses approximately 30% of the stays, 90% of the remaining stays are concentrated in the coastal tourism regions (Fig. 1), where the tourism industry is based mainly on the sun-and-beach model. Consequently, beaches are recognised as the principal resource for the development of this sector (e.g. Sardá et al., 2009). Therefore, SLR-induced erosion will significantly affect the available beach surface along the Catalan coast (Jiménez et al., 2017), resulting in a decrease in the key resources to be exploited. López-Dóriga et al. (2019) estimated different SLR scenarios and their implications for beach use by assessing the corresponding decrease in the recreational carrying capacity of beaches along the territory. The issue of how the economy will be affected remains uncertain.

Although there is vast literature on beach quality assessments from a recreational standpoint (Ariza et al., 2012; Pendleton et al., 2011; Roca et al., 2008), less attention has been paid to quantitatively assess the direct economic impact of beach recreation. It is well recognised that beaches are vital locations for recreation and key elements in the tourism industry (Houston, 2018). For instance, King and Symes (2003) suggested that the US economy would lose $2.4 billion in GDP annually if beaches were unavailable for recreation due to reductions in the beach width and the associated carrying capacity. More recently, Alexandrakis et al. (2015) estimated the tourism revenue losses due to eroded beaches in Greece. They estimated a loss of, on average, approximately 50 thousand €/m^2 per year after 10 years of shoreline retreat. Toimil et al. (2018) estimated the recreational value of different types of beaches in Asturias (Spain) as a function of their quality; they obtained a maximum estimated value of approximately 7000 €/m^2. For the Catalan coast, Ariza et al. (2012) assessed the value of beaches in areas with high tourist activity and found their value to be approximately 7 M €/ha in the peak of summer, a much higher value than other coastal areas (e.g. Edwards and Gable, 1991; Kline and Swallow, 1998; Silberman et al., 1992; Taylor and Smith, 2000).

In this study, we address the economic impact of SLR-induced erosion on Catalan beaches from the point of view of the demand, that is, the decrease in the affluence of tourists and revenues throughout the territory resulting from decreases in beach carrying capacities. From the perspective of demand, the economic value of tourism is calculated from the set of activities carried out by tourists and the associated expenditures.

The transversal character of tourism includes different economic branches, such as catering, commerce, and transportation (Baró, 2003), with multiple businesses and companies participating in the supply of goods and services to tourists as well as to the local population. Thus, to evaluate the contribution of tourism to the economy of a given territory, it is necessary to characterise the spending habits of tourists. Based on these, the direct and indirect effects they generate can be estimated. In this regard, the UNWTO has developed methodologies to assess the economic impact of tourism in the form of tourist satellite accounts (TSA) based on input/output (IO) tables. IO analysis measures the activity of producers and purchases of goods and services across the full spectrum of economic sectors (Vellas, 2011) and is one of the best methodologies to demonstrate how economic sectors are interrelated. It makes it possible to analyse the effects of demand changes in one economic branch on the other (Briassoulis, 1991; Fletcher, 1989; Sun, 2007).

It is worth mentioning that, together with erosion, coastal inundation is one of the main SLR-induced hazards. However, its induced

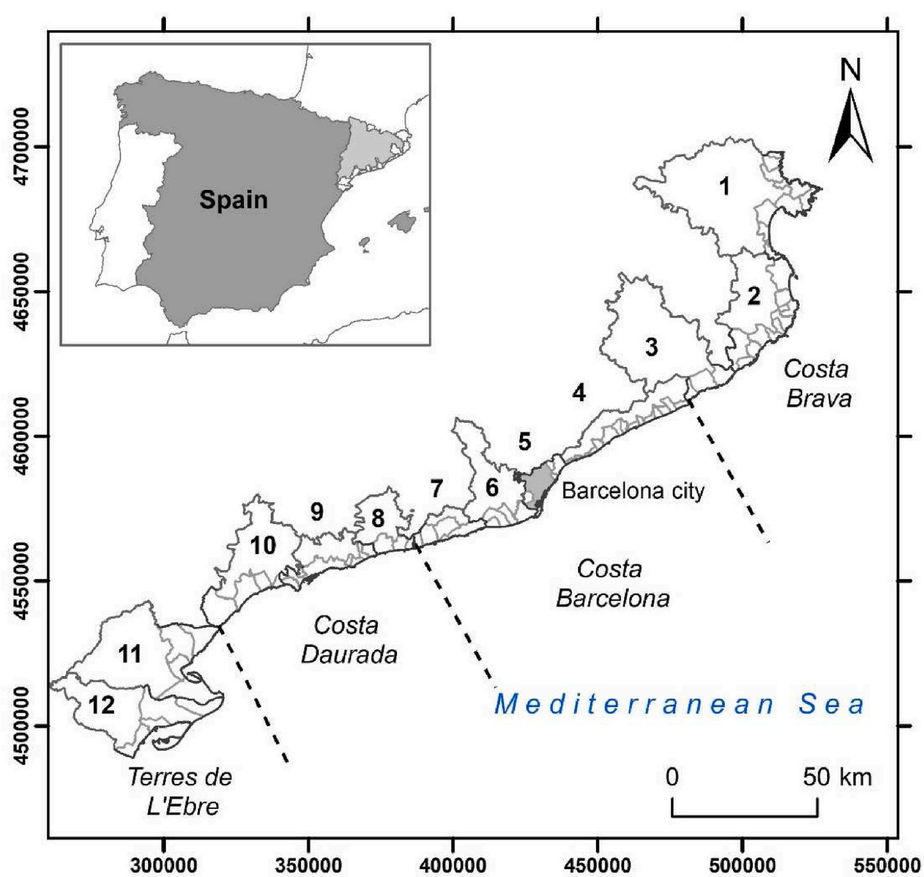

Fig. 1. The Catalan coast is divided into 12 coastal counties (see names in Table 1) and tourism coastal brands (names in italics). Smaller divisions in each county correspond to coastal municipalities. (Geographic coordinate system: ETRS89/UTM zone 31N).

impact on beach tourism is not as widespread as in the case of erosion, being very dependent on the coastal morphology and analysed scenario (e.g. Scott et al., 2012b; Fang et al., 2016). Along the Catalan coast, the affected area by permanent inundation is not significant except in low-lying zones such as the Ebro Delta (López-Dóriga et al., 2020). These flood-sensitive areas are dedicated to agriculture, while including sites of high natural value, and where beach tourism play a secondary role. Therefore, the potential impact of SLR-induced flooding on the beach tourism economy along the Catalan coast is not expected to be relevant, although it could have other implications on other sectors.

Within this context, the main aim of this study is to assess the impact of SLR on the economic contribution of coastal tourism in Catalonia, and hence, the potential influence on the current tourism model over the coming decades. To this end, we estimated the potential economic losses of SLR-induced beach erosion through IO analysis by assuming that the beach carrying capacity is linked to the potential tourism demand, and consequently, to tourism consumption and output. This is accomplished via two objectives: (i) application of IO analysis downscaled to the county scale, and (ii) assessment of the economic consequences of beach carrying capacity reduction under certain SLR scenarios. The practical goal of this research is to support coastal managers in the decision-making process and help them derive adaptation strategies for long-term coastal tourism planning. In this sense, this is in line with the work of Cramer et al. (2018) who identify the need of policies for the sustainable development of Mediterranean countries under the influence of climate changes, by mitigating increasing risks and considering adaptation options under the combination of climate and environmental changes.

2. Study area and data

2.1. Study area

The Catalan coast is located in the northeast Spanish Mediterranean region (Fig. 1). Its 600 km long coastline comprises a large diversity of coastal types, ranging from cliffs to low-lying areas, with approximately 270 km of beaches. Currently, approximately 65% of the beaches along the Catalan coast are affected by erosion (Jiménez and Valdemoro, 2019).

Administratively, there are 70 coastal municipalities in Catalonia, covering approximately 23% of the total territory, and they are grouped into 12 comarcas (territorial units similar to counties and hereafter referred to as counties) (Fig. 1). According to the Statistical Institute of Catalonia (IDESCAT) data, 63% of the total population inhabits coastal counties with an average population density of approximately 507 people/km^2, without considering Barcelonès, where it reaches 15,632 people/km^2. These values are significantly higher than the average for Catalonia, which was 239 people/km^2 in 2019, and some municipalities can triple in population density during the summer (IDESCAT, 2019).

Along the coast, the typology of beaches can be divided among two geographical areas: to the north and south of Barcelona. In the northern part, there are mostly reflective beaches with coarse sand and steep slopes. These include long beaches along the coastal plain of the Gulf of Roses, the long and narrow beaches located in Maresme County, and pocket and bay beaches in Costa Brava. In the south of Barcelona, most of the beaches are dissipative with fine sand and gentle slopes.

Current socioeconomic activities reflect the conditions typical of Mediterranean coastal areas where the economy is based on activities such as tourism, commerce, agriculture, and residential development (Sardá et al., 2005). Tourism is one of the primary economic sectors, contributing approximately 11% of the GDP of Catalonia (Duro and Rodríguez, 2011). From a tourism perspective, Catalonia is divided into nine tourism brands (Generalitat de Catalunya, 2015); they are located in bordering counties with relatively well-defined characteristics and with their own strategies of business positioning and management (e.g. Datzira-Masip and Poluzzi, 2014). Five of these brands are coastal and are showed in Fig. 1.

Tourism flows are not homogeneous throughout the territory, with most tourists concentrated in Barcelona and three of the coastal brands (Costa Brava, Costa Daurada, and Costa de Barcelona, Fig. 1), with the coastal counties accounting for 79% of the total number of accommodations in Catalonia. Tourism has also significantly influenced urban sprawl through secondary housing development, which has greatly contributed to the artificialization of the coastline and the reduction of natural spaces along the coast (e.g. Parcerisas et al., 2012; Cuadrado-Ciuraneta et al., 2017; Soto and Clavé, 2017). A classification of these coastal counties in homogeneous management units based on their socio-economic and environmental characteristics can be seen in Brenner et al. (2006).

The coastal county of Barcelonès, which includes the city of Barcelona, has been excluded from the analysis because of its particularities with respect to the problem analysed. The city of Barcelona is the main tourist attraction in Catalonia, the seventh city in Europe in terms of the number of international tourists (European Cities Marketing, 2019). Although its beaches are frequented by a substantial number of users, both local and foreign, it cannot be considered a classic sun-and-beach destination, because many of the users are not directly linked to the beaches, but to the city itself. Therefore, the analysis of the economic impact of SLR in this coastal county, assuming that visitors have the typical profile of a sun-and-beach destination, would be clearly overestimated and deserve a specific analysis.

2.2. Data

The data used in this study can be grouped into two categories: (1) economic data, which include the number of stays/visits in coastal counties and the tourism expenditure made, and the IO tables necessary for the economic analysis; and (2) the beach carrying capacity (BCC) data of the Catalan beaches.

2.2.1. Economic data

Economic data are used to characterise the contribution of tourism demand to the economy of coastal counties. Given the characteristics of the study area and considering the statistical data available, three typologies of coastal tourism demand were considered: (1) *tourists*, which are identified as those who stay overnight in the region; (2) *day visitors*, those who travel to the site for a one-day visit without staying overnight; and (3) *second home users*, those who have a second residence in the territory that it is partially used. All data refers to the year 2019.

The first element that determines tourism demand is the *number of overnight stays*. Tourist overnight stays were obtained from the official statistics provided by the IDESCAT, such as the number of travellers and overnight stays available for the tourism brands. They were then disaggregated at the county level according to the number of tourist places within the tourism brand, including hotels, campsites, rural houses, as well as other unregulated lodgings, such as Airbnb and other rental platforms. The estimates made by the Diputació de Barcelona (DIBA, 2020), obtained through surveys in selected municipalities, were used to characterise the tourists who do not stay overnight (i.e. *one-day visitors*). From these, an average ratio with respect to overnight stays was calculated and applied to all the coastal counties. Finally, to define the demand from people who have a second residence, data from the 2011 census (IDESCAT, 2011a) were used (this is the most recent available census), which have been updated according to statistics related to housing and population (IDESCAT, 2019). To estimate the number of overnight stays in the *second residences*, an average occupation of 2.82 people/home was assumed, which is the average value for the main residence in Catalonia, and a stay of 90 days/year (IDESCAT, 2011b). Table 1 lists the estimates of the number of stays in the coastal counties.

To characterise the *tourism expenditure* per *overnight stay* for each type of visitor, we gathered information from different statistical resources. The tourism expenditure surveys conducted by the Spanish

Table 1
Number of stays (in thousands) by coastal counties (representative by 2019).

tourism brand	coastal county	tourist (*Ntc*)	day visitors (*Nvc*)	second home (*Nrc*)
Costa Brava	1 1 Alt Empordà	5922	3092	13,664
	2 Baix Empordà	7663	2963	12,045
	3 Selva	8998	4376	5194
Barcelona	5 Barcelonès	23,283	9482	11,143
Costa de Barcelona	4 Maresme	9159	5689	6350
	6 Baix Llobregat	2730	9482	5124
	7 Garraf	2226	5689	3379
Costa Daurada	8 Baix Penedès	1387	4515	9858
	9 Tarragonès	10,972	3793	12,599
	10 Baix Camp	4728	3469	6948
Terres de l'Ebre	11 Baix Ebre	1053	2370	2165
	12 Montsià	524	2431	1705

Ministry of Industry, Trade and Tourism (Egatur, 2019), and the Tourism Activity Index developed by the Autonomous University of Barcelona (Duro, 2014) provide information on the expenditures of tourists arriving in different destinations of Catalonia. This expenditure data differentiates between different factors that expenditure, such as origin, means of transport, and type of accommodation. Likewise, data from the National Statistical Institute (INE) allowed us to differentiate the expenditures per tourism region. These sources offer spending figures characterised by the type of accommodation (hotels, campsites, and rural houses). Data from INE (2020a) and the Tourism Laboratory of DIBA (DIBA, 2020) were used to calculate the average expenditure for the one-day visitors. Finally, to estimate the expenditure made by second home users, the level of expenditure per inhabitant in Catalonia and consumption patterns were analysed (INE, 2020b). For this study, an average value of 36.8 €/person·day was considered. This figure does not include any component related to the construction and maintenance of the dwelling, because it is intended to be the most restrictive for the concept of tourism expenditures.

The data used to characterise the economy of Catalonia were obtained from the official statistics provided by IDESCAT (2019). The indicators used are GDP and jobs for each coastal county, which is the most detailed scale available (Table SM1 in Supplementary Material). To contextualize these values, the coastal counties of Catalonia produced approximately 130,420 M € in terms of GDP and 1.83 M jobs in 2019, with Barcelonès County accounting for 55% and 63% of the total GDP and jobs.

Finally, IO tables are necessary to analyse the impact of the tourism sector and its repercussions on economic parameters, such as income and employment. For Catalonia, the IDESCAT developed IO tables at the regional level for the years 2001, 2005, and 2011, and partially for 2014. In this study, we used the IO tables corresponding to the year 2011 (IDESCAT, 2011b), they were disaggregated into 82 productive sectors and updated to 2014 values by adjusting the two basic matrices for the IO analysis (technical coefficient and Leontief inverse matrix). This is a widely applied method (Brand, 2012). This update was based on macroeconomic data on the evolution of production and business account samples of various sectors of the Catalan economy, which allowed for the adjustment of the productive relationship between them.

2.2.2. Beach carrying capacity

The BCC values used in this study were obtained from the study conducted by López-Dóriga et al. (2019), who developed a model to assess the evolution of the recreational carrying capacity of Catalan beaches. The BCC considers each beach, the available surface, spatial pattern of beach use in the area, and beach typology that determines the maximum density of users allowed without affecting the quality of recreational experience.

To compute the BCC, the current beach dimensions were estimated from aerial photographs obtained from the Institut Cartogràfic i Geològic de Catalunya (ICGC). Their projection in time was achieved by applying decadal-scale rates of shoreline evolution under the current conditions obtained from Jiménez and Valdemoro (2019), with the SLR-induced shoreline retreating under the considered SLR scenarios by applying the Bruun's rule (see details in López-Dóriga et al., 2019).

The SLR projections used in this work were based on the IPCC AR5 RCP4.5 and RCP8.5 scenarios (50% probability level, Church et al., 2013). In addition, we have also included a high-impact (H+) scenario that, although unlikely to occur, is relevant from a risk-management standpoint (e.g. Hinkel et al., 2015). This scenario used the projection of sea level at a 95% probability of the RCP8.5 steric component (see Jevrejeva et al., 2014 for details). These scenarios for the year 2100 relative to 2010, with SLR of 0.49 m, 0.70 m, and 1.70 m.

3. Methods

3.1. General methodological framework

To assess how SLR will potentially affect the economy directly related to coastal tourism, we developed a conceptual model for the study area which is applicable to a typical sun-and-beach tourism mature destiny. In essence, the model assumes that if the integrated carrying capacity of existing beaches in a given spatial unit decreases, this will affect the tourism-related economy of the area. The key assumptions made in the model are as follows.

- Beaches are the main natural assets for tourism development, with the user distribution related to current beaches' characteristics (e.g. density of use, dimensions, landscape). Because this is a mature destiny, any variation in the BCC due to a variation in the useful beach surface is directly transferred to the potential number of users of the beach.
- Users have spatial mobility and can visit any beach within a certain distance from their place of stay. Ideally, this distance would cover beaches within a radius from the original location considering the existing transport network and user preferences (e.g. Pueyo-Ros et al., 2017). However, for the sake of simplicity, we assume that mobility is well represented by the scale of the county. In this regard, it was assumed that counties along the Catalan coast have homogeneous environmental and socio-economic characteristics (Brenner et al., 2006), and they are the basic units to form a tourism brand (Fig. 1). In practical terms, this implies that users within a given county can use any beach in that county, if the beach can accommodate the user without increasing the maximum permitted density of use.
- Consequently, if the potential number of users of a given beach decreases due to a loss of useful surface, users would be redistributed to other beaches in the county (e.g. López-Dóriga et al., 2019). This is equivalent to characterising each county by an integrated BCC, which determines the maximum number of potential users within the county beaches.
- SLR-induced erosion (as well as current coastal dynamics) will decrease (modify) the county-integrated BCC, which implies a loss in the number of potential beach users, and consequently, a proportionate reduction in the incurred tourism expenditure. This variation in tourism expenditures per county can then be translated to changes in GDP and employment within the county using an IO model downscaled at the county level.

Therefore, the proposed methodological framework consists of three key steps (Fig. 2): (i) assessment of the BCC integrated at the county scale, (ii) assessment of the incurred tourism expenditure, and (iii) application of the IO model to measure the economic impact of changes

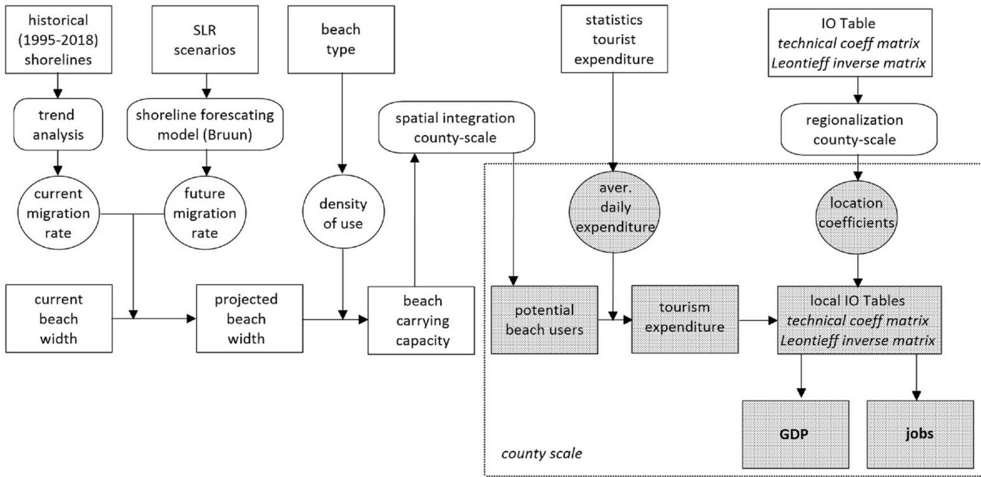

Fig. 2. Methodological framework to assess SLR impact on the sun-and-beach based coastal tourism economy. Shaded boxes indicate values given at the target spatial scale, here evaluated at the county level.

in tourism expenditures.

3.2. Assessment of BCC

The carrying capacities of the Catalonian beaches under different sea level scenarios were assessed following López-Dóriga et al. (2019). To do so, we first calculated the time evolution of the available surface of the Catalan beaches by applying shoreline evolution rates corresponding to each tested scenario. The resulting surface at a given time under the analysed scenario was then used to estimate the allowable number of potential users that could be physically accommodated on each beach. The number of users depends on three parameters: (i) the available beach surface or equivalent beach width, which varies with time as the shoreline responds to forcings under the selected sea-level scenario; (ii) the resting area, which is the beach surface occupied by users, which for Spanish Mediterranean beaches are concentrated in a fringe of 35–40 m wide from the shoreline; and (iii) the maximum density of use (minimum beach surface allowed per user), which depends on the beach type (urban, semiurban, or rural) and intensity of use (high, moderate, low). These variables were then used to assess the influence of shoreline dynamics on the recreational capacity of the beach according to the model proposed by Valdemoro and Jiménez (2006).

Once the BCC was estimated for each beach along the coast, their values were spatially integrated within a given management unit (defined by the county) to assess the overall carrying capacity of the unit.

Additionally, to investigate the potential influence of BCC on the tourism economy, it would be worthwhile to assess whether the available BCC per county is sufficient to accommodate all the potential users. Because the BCC indicates the available daily carrying capacity, the annual users per county were normalised by time (365 days) to obtain the potential daily beach demand. This number was then compared with the BCC to obtain the *potential beach occupancy* (PBO),

$$PBO = \textit{number of potential visitors} \text{ per } \textit{day} \, / \, BCC \quad (1)$$

Values over 1 indicate that existing beaches in the county would not be able to provide enough space to accommodate all the potential users, even if they are uniformly distributed throughout the year. Considering that sun-and-beach tourism in the Mediterranean is strongly seasonal (e.g. Duro and Turrión-Prats, 2019), with most users concentrated between May and September, PBO values exceeding 0.40 would indicate a situation approaching collapse, because the beaches would provide an insufficient BCC to absorb the potential demand during the bathing season. To assess how this would affect different types of potential users, this value was separately calculated for the three types of potential users (tourists, one-day visitors, and second-residence users). The priority for calculating the PBO is that which is associated with tourists because they have the largest associated expenditures (see Table 2), and they visit the area mostly during the bathing season. The second priority is given to one-day visitors, who are mostly locals enjoying the site during good weather conditions.

For counties with large PBO values, the analysis could be further refined by considering the monthly variability in demand. First, the potential demand by comarca is distributed monthly considering the annual affluence curve, which indicates the percentage of visitors throughout the year. This curve is directly built from tourism statistics, and although disaggregated data per county are available, for the sake of simplicity, we have built a representative affluence curve for the entire coastal territory by averaging all the data from the last 15 years (see Fig. 3). Next, we distributed the visitors to the county by applying the percentage corresponding to each month to obtain the potential daily beach demand every month throughout the year. Finally, this number was compared with the BCC of the comarca to obtain the PBO.

3.3. Assessment of tourism expenditure

Tourism expenditures include the declared expenditure of all types of users for coastal counties along the Catalan coast. These estimations were obtained from the official tourism statistics (see Section 2.2.1), and they are given for each tourism brand for both tourists and one-day visitors, whereas a constant value has been taken for the second-home

Table 2
Average daily expenditures (in €/person·day) per coastal county in 2019.

Coastal county	Tourist (Gt)	one-day visitors (Gv_c)	Second home (Gr_c)
Alt Empordà	118.1	41.3	36.8
Baix Empordà	118.1	41.3	36.8
Selva	118.1	41.3	36.8
Maresme	121.0	42.3	36.8
Barcelonès	176.7	61.8	36.8
Baix Llobregat	150.0	52.5	36.8
Garraf	155.6	54.4	36.8
Baix Penedès	120.0	42.0	36.8
Tarragonès	120.0	42.0	36.8
Baix Camp	120.0	42.0	36.8
Baix Ebre	111.2	38.9	36.8
Montsià	111.2	38.9	36.8
Average	**128.3**	**44.9**	**36.8**
Av. w/o Barcelonés	**123.9**	**43.4**	**36.8**

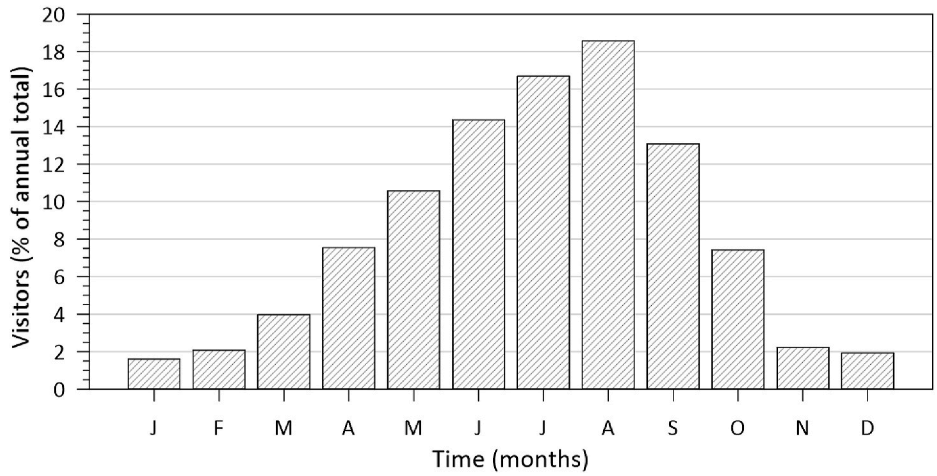

Fig. 3. Average monthly distribution of visitors (hotels) to all coastal counties of Catalonia (excluding Barcelonés (5)) during the period 2006–2019.

residents. To apply this at the county level, the expenditure values of a given tourism brand were applied to each county within it.

Because the statistics of daily tourist expenditures are given for each type of installation, the average expenditure, Gt, was calculated using Eq. (2), where GH is the average daily expenditure of those staying in hotels, PH is the number of overnights in hotels, and GC, PC, GR, and PR stand for the same variables for campsites and rural cottages, respectively, and PT is the total number of overnights.

$$Gt = ((GH * PH) + (GC * PC) + (GR * PR)) / PT \tag{2}$$

Finally, the total tourism expenditure for each coastal county, GT_c, is obtained by applying Eq. (3) where, Gt_c, Gv_c, and Gr_c, are the daily average expenditures per tourist, one-day visitors, and second-residents, respectively, and Nt_c, Nv_c, and Nr_c, are the number of tourists' overnight stays, visits, and second-residents, respectively, whereas the subscript indicates that they are evaluated in the county c.

$$GT_c = (Gt_c * Nt_c) + (Gv_c * Nv_c) + (Gr_c * Nr_c) \tag{3}$$

The impact of SLR on the tourism-related economy was estimated through 2050, 2075, and 2100. Although the use of long-term scenarios is common in physical-impact assessments, its application for forecasting economic impacts is not a straightforward task because of the large uncertainties involved (e.g. Christensen et al., 2018). In this work, this was simplified by considering the expected decrease in tourism expenditure with respect to the current economy due to a potential decrease in the number of beach users. This assumption simplifies the assessment without making any hypothesis about the economic development at the county level over the next 80 years.

3.4. IO analysis

The input-output (IO) analysis is a quantitative technique that represents the existing interdependencies between different sectors within the economy of a region. Originally developed by Leontief (1936), this model is commonly used to estimate the impacts (positive or negative) of economic shocks and analyse the domino effect throughout the entire economy (Miller and Blair, 2009). In other words, it describes the flows of money between sectors through the economy of a region. The magnitudes of these flows between sectors are recorded in a table, with the sectors of origin (producers, inputs) and destination (purchasers, outputs), and constitute the core of the IO analysis.

Thus, the IO table allows us to convert expenditures and investment data into macroeconomic variables, such as GDP and employment, using a technical coefficient matrix and the Leontief inverse matrix. The matrix of technical coefficients provides a simplified view of the technical production relationships that exist between the various branches of an economy. It is configured as a square-matrix of "n" rows and "n" columns indicating the number of branches into which the total economic activity is disaggregated; in this case into 82 economic branches. Therefore, the matrix of technical coefficients allows us to analyse the effects of the changes in the economic activity. The Leontief inverse matrix measures the successive effects on the economy because of the initial increase in the production of a branch of economic activity. In other words, if an increase in production initially requires a greater demand for intermediate consumption to be carried out, this in turn is produced by other branches using the new intermediate consumption, and so on.

When applying the IO model, three types of effects can be distinguished: (i) direct effects derived from the income received by the different productive factors due to the consumption and expenditures of the different types of visitors; (ii) indirect effects caused by the increase in economic activity related to tourism and the investments made in complementary activities; and (iii) induced effects generated by the increase in the economic activity associated with the expenditures made by people directly or indirectly linked to tourism. The sum of these effects makes it possible to evaluate the overall economic impact of tourism in a given territory.

The IO tables differentiate the economic flows within Catalonia, the rest of Spain, and in relation to other countries, which allows us to know how the GDP and employment generated in the territory are distributed by quantifying the spillover effect. This effect consists of an action that is carried out in a certain territory (investment or expenditure) that affects the economy of another. In the case of tourism, with a wide range of related goods and services, these spillover effects are usually significant (e.g. Kadiyali and Kosová, 2013).

Finally, to assess the effects on a smaller scale, it is necessary to apply regionalisation techniques to the IO tables (Álvarez, 2001). The most widely used technique to downscale the IO tables is the use of location coefficients (Flegg et al., 1997; Flegg and Tohmo, 2011) and applying them to the national coefficient of the IO table (Brand, 2012). In this study, the approach of Garola (2019) for the regionalisation of the IO tables was adopted, which is given by

$$A^r_{ij} = A^N_{ij} * q_{ij} \tag{4}$$

where A^r_{ij} is the coefficient of the IO table at the county scale, A^N_{ij} is the coefficient of the IO table at the regional scale (in this case, Catalonia), and q_{ij} are the location coefficients developed from the existing economic information. For Catalonia, the economic macro-magnitudes are available for counties and large cities. These location coefficients represent the existing relationship in the production of sectors between the counties and Catalonia (Eq. (5)), and by definition, are less than one, reflecting the fact that each county is part of a higher administrative unit.

The location coefficient q is given by

$$q_i = \left(\frac{x_i^c}{X^c}\right) \Big/ \left(\frac{x_i^N}{X^N}\right) \quad (5)$$

where x_i is the production of sector i, X is the total production, and superscripts c and N refer to county and regional values, respectively.

These location coefficients enable the creation of new matrices of technical coefficients and inverse Leontief matrices to introduce the local impact, and therefore, to assess what part of the economic impact associated with tourism expenditures has an impact on the economy at the county level. The application of this tool makes it possible to capture the effects of tourism activity in a given county in order to calculate GDP and jobs.

4. Results

4.1. Beach Carrying capacity (BCC)

The BCC values integrated at the county scale along the Catalan coast under scenario RCP8.5 are shown in Fig. 4 (values for all scenarios and time horizons are available in the Supplementary Material, Table SM2). The current average BCC value per county along the Catalan coast is 131,000 users, although it exhibits a significant variability, with Maresme (4) as the county with the highest value due to its long coastline and the urban and intensive use of its beaches. La Selva (3) has the lowest BCC because of its relatively small beach space. The effect of beach type on the BCC is clearly observed in the southernmost counties (11, 12), which, although they include the exceptionally long coastline of the Ebro Delta, are composed of low-density rural beaches, and this combination results in a relatively low BCC.

As it can be clearly seen in Fig. 4 for scenario RCP8.5, SLR produces a significant decrease in the BCC along the entire coast. Overall, assuming that the maximum density of use is maintained for all beaches, the integrated BCC of the entire Catalan coast is reduced by 40%, 60%, and 70% by 2050, 2075, and 2100, respectively. Under the RCP4.5 scenario (Fig. SM1a in Supplementary Material), the expected reduction in the BCC is of the same order of magnitude (37%, 54%, and 63%), whereas under the H+ scenario (Fig. SM1b in Supplementary material), a drastic decrease in the BCC was predicted (57%, 77%, and 86%). The county most sensitive to the BCC change due to SLR-induced erosion is La Selva (3), where the expected reduction rates under the RCP8.5 scenario are significantly higher than the average at 60%, 85%, and 98% by 2050, 2075, and 2100, respectively. It must be considered that the estimated decrease in the BCC also includes the contribution of shoreline retreat under the current conditions, which is a dominant process in approximately 65% of the sedimentary Catalan coast (Jiménez and Valdemoro, 2019).

When these variations in the BCC are integrated with the potential users of each county, the spatial differences across the territory are accentuated. This is shown in Fig. 5 by the evolution of the potential beach occupancy (PBO) of each county under the RCP8.5 scenario (its evolution under the RCP4.5 and H+ scenarios is displayed in the Supplementary Material, Fig. SM2 and Fig. SM3, respectively). Because the analysis is performed assuming a constant demand (number of users), these variations reflect the variations in the BCC for each county, with increasing values of the PBO indicating a lower capacity to accommodate potential users of the county's beaches. Notably, these occupancy values only account for the use of the beach by the three types of visitors considered here, without accounting for the potential use by the local population, which would further increase the demand for beach space.

Thus, the most critical areas, indicated by the highest PBO values, are found in the two most significant tourism brands, Costa Brava (comprising counties 1 to 3) and Costa Daurada (counties 8 to 10). The highest value is found in La Selva (county 3 of the Costa Brava), where, at present, the PBO associated with tourists already reaches a value of 0.4, which implies that the entire beach surface of the county should be fully occupied by this type of user during the entire bathing season. A similar behaviour was also found at Tarragonés (comarca 9 at Costa Daurada), although with a lower beach occupancy.

When time projections were considered, as expected, the PBO increased in all areas of the Catalan coast, although with significant spatial variation (Fig. 5). The greatest impact is found in the areas with the highest demand, that is, counties in Costa Brava and Costa Daurada. Thus, when only considering tourists, La Selva (3) would be totally collapsed by 2050, with PBO values close to 1, while Tarragonés (9) would have reached a value close to 0.4, which is the limit of collapse for the bathing season in 2075. When considering the other types of users, visitors and second-residence, the PBO increases further, exceeding the critical value of 1 in many areas, which indicates that even considering all the days throughout the year to accommodate users on beaches of the area, the existing surface will be insufficient.

To illustrate the influence of the seasonal nature of beach use in the Mediterranean, Fig. 6 shows the monthly evolution of the PBO associated with tourist users for the most sensitive counties in the two main tourism brands, La Selva (3) in Costa Brava, and Tarragonés (9) in Costa Daurada, under the RCP8.5 scenario. For example, in La Selva, by 2050, the number of potential beach users (only considering tourists) will be higher than 1 during the entire bathing season (May to September), which should indicate a collapse of the beaches of the county because they would have a carrying capacity far below that needed to absorb the existing demand. These figures will increase further if we add the remaining potential users (one-day visitors and second-residence users). Furthermore, the evolution of the PBO for Tarragonés exhibits a similar trend, although the values are lower, indicating that although the

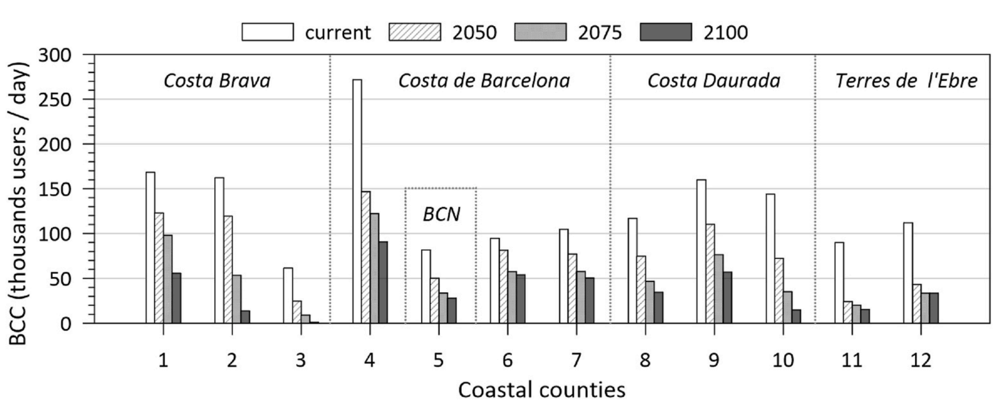

Fig. 4. The evolution of the BCC for coastal counties along Catalonia under the RCP8.5 SLR scenario (names for each numerical code are listed in Table 1). Dashed lines delimit the tourism brands where the counties are included (see Table 1).>

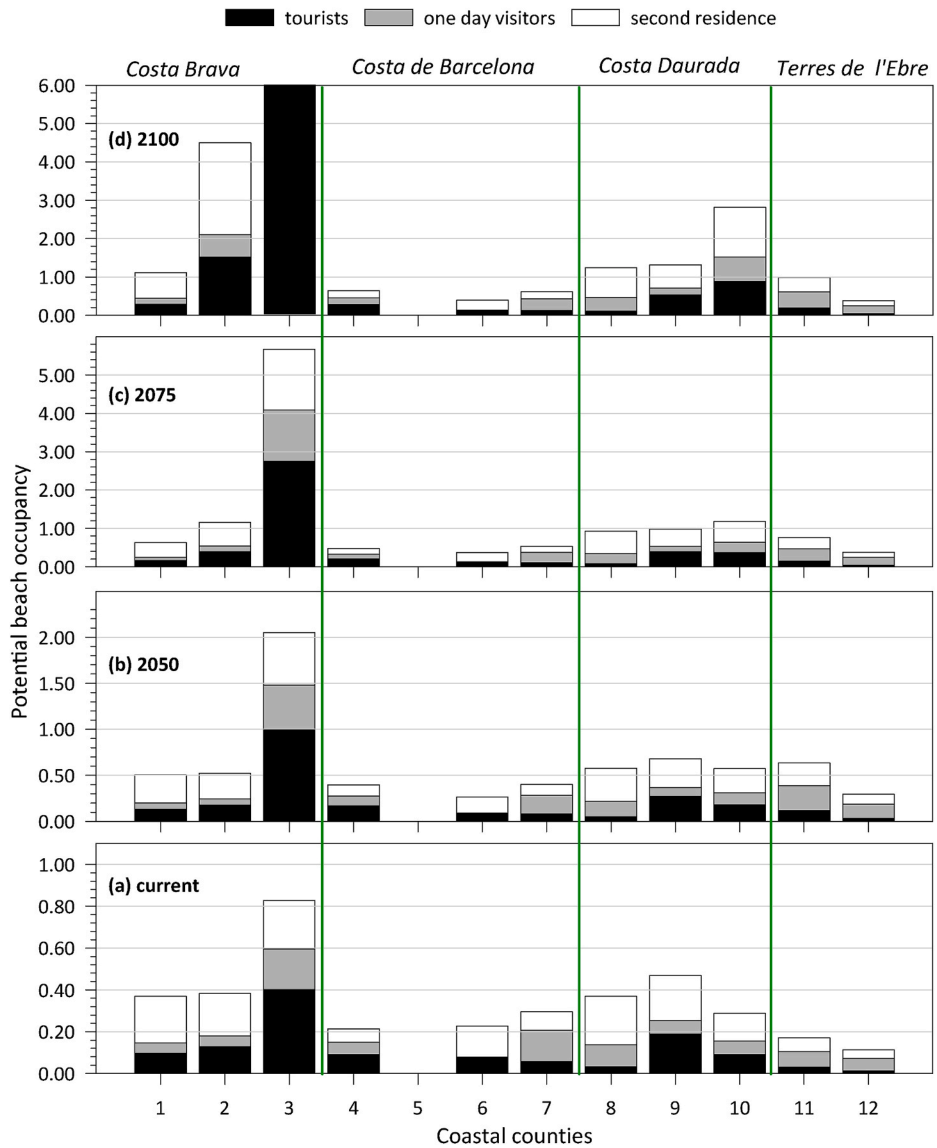

Fig. 5. Potential beach occupancy (PBO) per type of users along coastal counties of Catalonia (names for each numerical code are shown in Table 1) at different time horizons under the RCP 8.5 scenario. Vertical lines delimit tourism brands. For 2100, only the PBO associated with tourists is shown for La Selva (comarca 3) to avoid distortion in the y-axis to include other types of users (out of scale). (Note that the Barcelonés county (5) is not shown to avoid the effect of the city of Barcelona.

situation worsens over time, it is not as critical as it is in La Selva. The adverse evolution of the PBO over time will be aggravated in the H+ scenario (see Fig. SM3 in Supplementary Material), as many beaches will disappear completely, especially in the counties included in the most vital tourism brands, Costa Brava and Costa Daurada.

4.2. Economic contribution of tourism

The average daily expenditures of all the users along the Catalan coast are listed in Table 2, indicating that tourists spend the most, followed by one-day visitors and second-home users in a ratio of 3.5:1.2:1. As for the spatial distribution of the expenditures, tourists and one-day visitors in the counties closest to Barcelona are those with the highest expenditures reported (see Table 2).

When this daily expenditure is applied to all the visitors along the Catalan coastal counties in 2019, the total tourism expenditure is approximately 16,933 M €, with 64%, 20%, and 16% spent by tourists, one-day visitors, and second-home users, respectively (Table 3). Among all the counties, Barcelonès stands out, reflecting the substantial magnitude of Barcelona as a tourist centre. Notably, although Barcelona beaches are used intensively throughout the year, the city itself is the main interest of tourists. As mentioned above, the economic impact of SLR on Barcelona would be overestimated if we apply the methodology used for the other counties, so it is eliminated from the analysis. Thus, the total expenditure in the coastal counties, excluding Barcelonés, is 11,823 M €, which means that nearly 30% of the tourism expenditures are made in Barcelona.

Notably, these figures are derived from the expenditures generated by tourists from a comarca within that unit, which is a restrictive criterion in which each comarca is considered a closed unit. Therefore, although tourism expenditures in a given comarca generate indirect and induced productive activities in other areas, these links have not been considered.

Using tourism expenditures as a vector of demand and applying the IO methodology, it is possible to find an increase in production generated by such expenditure. Thus, Table 4 provides the estimated economic impact of tourism activities in the coastal counties, excluding Barcelonés, at 7498 million, which represents 12.8% of the total GDP of these counties. Likewise, this sector provides more than 100,000 jobs, representing approximately 13% of the total employment in coastal

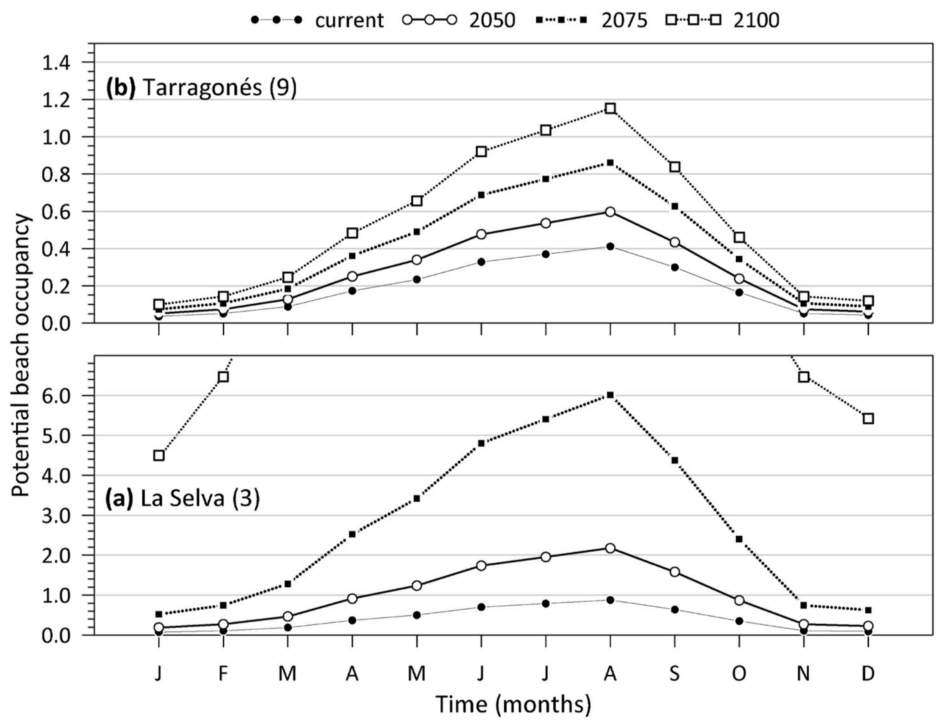

Fig. 6. Monthly PBO per type of user in **(a)** La Selva (3) and **(b)** Tarragonés (9) counties at different time horizons under the RCP 8.5 scenario. The PBO curve for La Selva in 2100 is truncated at a value of 7.0, owing to the high values reached.

Table 3
Tourism expenditures (in M €) per coastal county in 2019.

Coastal county	Tourist	one-day visitors	Second home	TOTAL
Alt Empordà	700	128	502	1329
Baix Empordà	905	122	443	1470
Selva	1063	181	191	1434
Maresme	1109	241	233	1583
Barcelonès	4114	586	410	5110
Baix Llobregat	410	497	188	1095
Garraf	346	310	124	780
Baix Penedès	167	190	362	718
Tarragonès	1317	159	463	1939
Baix Camp	568	146	255	969
Baix Ebre	117	92	80	289
Montsià	58	95	63	215
Total	**10,873**	**2745**	**3314**	**16,933**
w/o Barcelonés	**6759**	**2159**	**2904**	**11,823**

Table 4
Tourism GDP (in M €) and jobs in coastal counties in 2019.

Coastal county	GDP (M €)	Jobs
Alt Empordà	813	10,300
Baix Empordà	895	11,500
Selva	884	9900
Maresme	881	14,100
Barcelonès	5158	85,600
Baix Llobregat	901	11,900
Garraf	491	8000
Baix Penedès	441	5900
Tarragonès	1265	14,700
Baix Camp	615	10,800
Baix Ebre	178	2400
Montsià	134	2300
Total	**12,656**	**187,400**
w/o Barcelonés	**7498**	**101,800**

counties. For Barcelonés, tourism activities contribute more than 5000 million € and 85,000 jobs.

These results were obtained by adapting an IO model for each region. Each of these models also generated impacts outside the territory, which is known as the spillover effect. The sum of these spillover effects amounts to 4352 million €, part of which can be attributed to Catalonia, although it has not been attributed to any specific region. Finally, to properly interpret these results, it should be considered that the model provides annual results, whereas beach/coastal tourism activities have a strong seasonal character.

Fig. 7 illustrates the effect of tourism on the GDP of each county. As can be seen, there is a significant variability, ranging from 4% in Baix Llobregat (6) to 29% in Baix Empordà (2). In any case, these values should be interpreted with caution because they depend on the importance of tourism and the existence of other activities. Thus, the high values obtained for Baix Empordà (2) and Baix Penedès (8) reflect their significance as areas that are highly specialised in tourism, combining both tourists and second homes. They correspond to Costa Brava and Costa Daurada, the most well-known coastal tourist brands in Catalonia.

4.3. SLR-impact on the economy

The impact of the SLR on tourism GDP in each coastal county relative to the current values under the analysed SLR scenarios is displayed in Fig. 8. As expected, the percentage of income associated with tourism decreases over time and with the magnitude of the SLR. In fact, the drop in the tourism GDP would be significant even without considering SLR due to the dominant erosive behaviour of Catalan beaches (Jiménez and Valdemoro, 2019). This is noticeable for all counties even at the short time scale (by 2050), although the impacts of different magnitudes reflect the spatial variability in the beaches' dimensions and current shoreline evolution. As expected, when considering the effect of SLR under the different scenarios, the decrease in tourism GDP is much more pronounced and generalised as we move from RCP4.5 to the H+ scenario, which is especially relevant as the time scale increases (by 2100). A drastic example would be the counties of the Costa Brava tourism

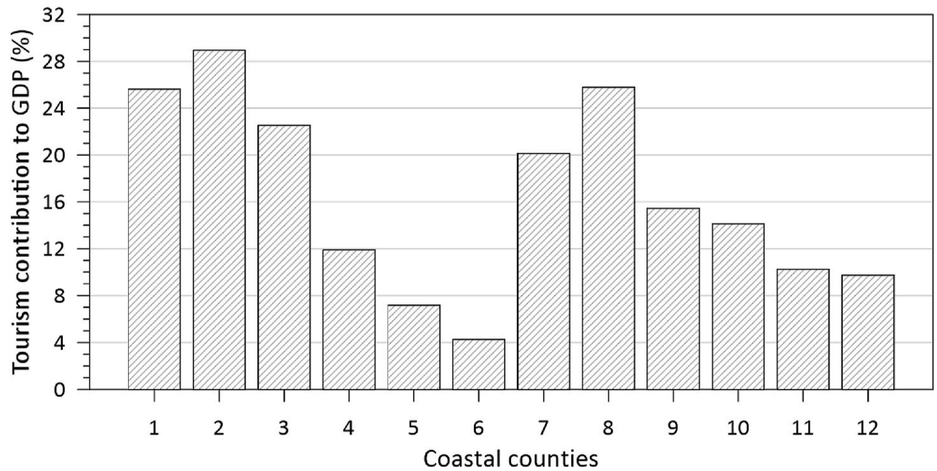

Fig. 7. Contribution of tourism to GDP (as a percentage of total GDP) for each coastal county in 2019.

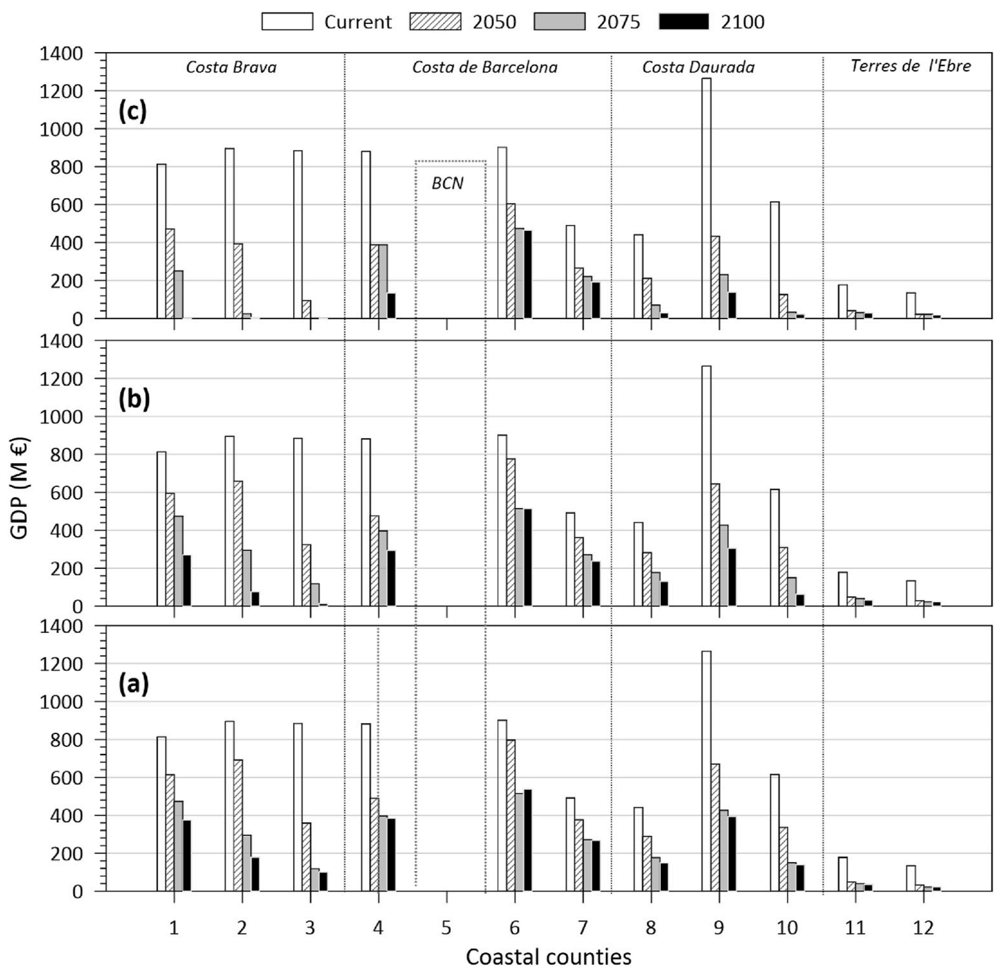

Fig. 8. Effects of SLR on the GDP of Catalan coastal counties under different climatic scenarios by 2050, 2075, and 2100. **(a):** RCP4.5; **(b):** RCP8.5; **(c):** H+.

brand, which could lose all the sun-and-beach tourism activities in the most extreme (H+) scenario due to the expected disappearance of their beaches.

Considering RCP8.5 as a reference, and not including Barcelonès, the coastal counties of Baix Empordà (2), La Selva (3), and Tarragonès (9) will suffer the greatest reductions by losing more than 800 M € each in their tourism GDP by the end of the century. In other words, Catalonia's most valuable coastal tourism brands, Costa Brava and Costa Daurada, will be the most economically affected, with an expected GDP loss of approximately 2200 € and 1820 million €, respectively.

To put these tourism economic figures in the context of the overall economy, Fig. 9 illustrates the SLR-induced effect on the total GDP of each county. As expected, the greatest impacts on total GDP will occur in coastal counties that are highly specialised in tourism, mostly belonging to the Costa Brava and Costa Daurada brands. For long-term projections (by 2075 and beyond), the decline in the total GDP in Baix Empordà (2),

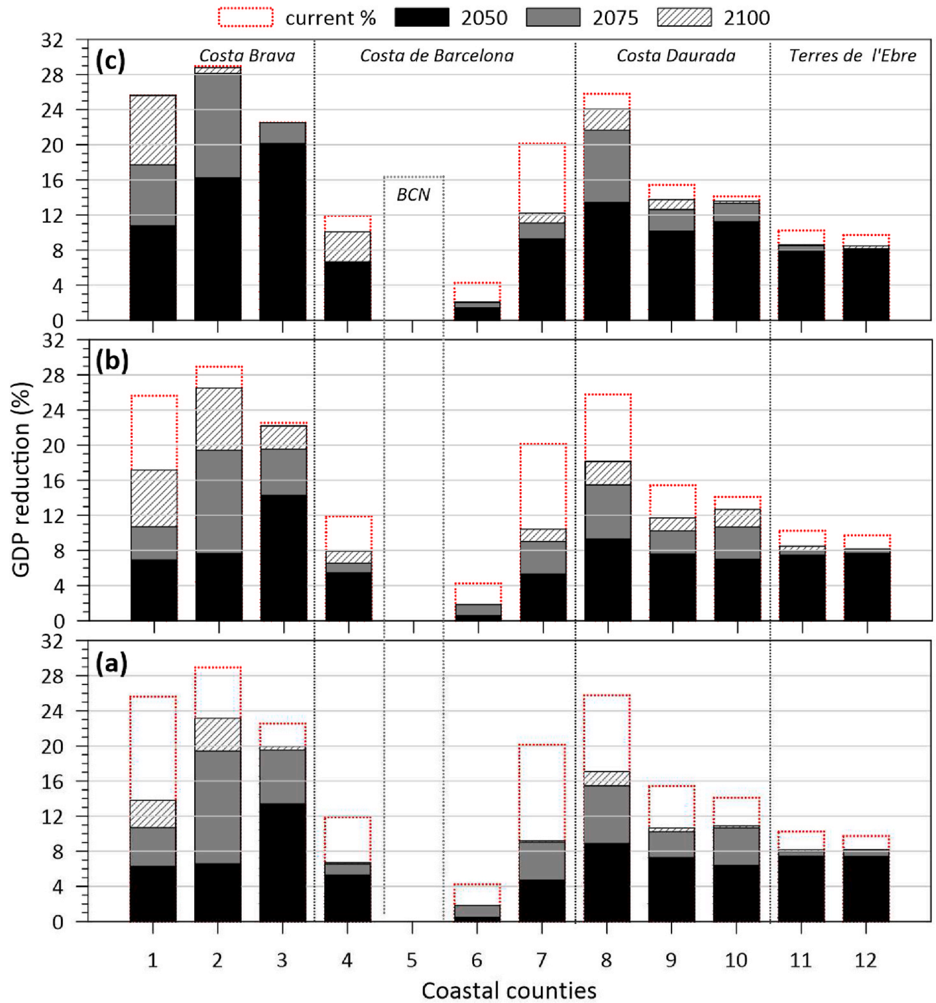

Fig. 9. Reduction in total GDP (in %) relative to 2019 values for each coastal county under different climatic scenarios by 2050, 2075, and 2100. **(a):** RCP4.5; **(b):** RCP8.5; **(c):** H+. The dashed red line bar indicates the current (2019) contribution of tourism to total GDP in each county.

La Selva (3), and Baix Penedès (8) would be between 16% and 19% (by 2075) and between 18% and 26% (by 2100) under the RCP8.5 scenario, reaching a maximum decrease of approximately 29% under the extreme H+ scenario.

5. Discussion

5.1. Methodological aspects

In this study, we propose a methodology to assess the potential impact of SLR on the economy of mature sun-and-beach tourist destinations and apply it to a region representative of Mediterranean conditions, Catalonia. The method relates the expected decrease in the recreational carrying capacity of beaches with the decrease in total tourism expenditures, which are transferred to tourism GDP using an IO model. Because the model is based on the impact of a decrease in the number of potential visitors to a given destination, this model could also be used to assess the potential economic impact of other types of events affecting tourist affluence, such as the COVID-19 pandemic (e.g. Suriñach and Romaní, 2020).

We implicitly assumed a system in equilibrium in which the maximum number of tourists/users within a given county is controlled only by the integrated recreational carrying capacity of its beaches. This corresponds to a mature system in which the typology of users is well defined and adapted to local conditions; therefore, the users have selected the site based on the characteristics of existing beaches at their maximum allowable density of use (e.g. Roca et al., 2008; Botero et al., 2013; Lozoya et al., 2014; Cabezas-Rabadán et al., 2019). To assess the evolution of the BCC, the maximum density of use of the beaches within a given county is not allowed to vary over time so the user profile of each site is not altered. By increasing the density of use at certain beaches, the carrying capacity can be maintained within a certain range to support future demand. However, scenarios of higher user density would lead to overcrowding, which would affect the attractiveness of the area, and consequently, its recreational use (e.g. Ariza et al., 2008, 2010). In any case, the changes in beach morphology could affect user preferences, and therefore, the beach choice by tourists (e.g. Pendleton et al., 2011; Botero et al., 2013; Dodds and Homes, 2019). This implies that unexpected variations in tourist numbers due to external factors such as economic crises, political issues, natural disasters (e.g. Hall, 2010), or health issues such as the COVID19 pandemic (Gössling et al., 2020) are not considered. Possible long-term variations due to other effects of climate change, such as a decrease in destination comfort (e.g. Bujosa and Rosselló, 2013), have also not been considered. In summary, the adopted approach can be considered as the most plausible hypothesis, apart from the unlimited number of possible scenarios that could be given for such long-term projections. With this, a decrease in the BCC would lead to a reduction in the number of users to maintain the density of use, and consequently, a reduction in tourism expenditures in the same proportion.

Tourism expenditures initiate the economic impact of tourism on a region. Thus, the first data required are how much visitors spend on services and goods in the local economy (Frechtling and Horváth, 1999). Quantifying tourism expenditures is a challenging task because it involves many aspects to consider, such as (i) the proper definition of the tourist–visitor concept, (ii) the hypothesis made about expenditure levels, and (iii) the application of models to obtain the economic magnitudes of such expenses. Here, we have combined existing official statistics on tourism expenditures to obtain representative values for each coastal county of Catalonia. The implicit hypothesis is that this spatial variability in tourism expenditures reflects the existing spatial variability in used natural resources (beaches), tourism services and infrastructures (e.g. hotels), and user profiles. This is similar to the relationship found between prices in campsites and hotels found along the Spanish coast (e.g. García-Pozo et al., 2011; Rigall-I-Torrent et al., 2011).

The model was applied assuming that tourist (unit) expenditures does not suffer any temporal variations due to external or internal causes. This is not necessarily true, but as our aim is to make a relative assessment with respect to the current situation, it will provide the expected changes due to SLR for the remaining variables that affect the total expenditures, apart from the number of visitors. However, this could be complemented by including a parallel analysis of the evolution of tourism expenditures.

Once the variations in the total tourism expenditures have been assessed, the economy-wide effects are assessed using an IO model. The key methodological constraints are associated with the inherent assumptions of the IO methodology, such as the use of constant scale returns or the structural stability hypothesis (Miller and Blair, 2009) and the applied regionalisation technique (Flegg and Tohmo, 2011). In this sense, one of the primary constraints is the limited availability of the economic magnitudes disaggregated by sector at small spatial scales. Here, we have solved this by using location coefficients which have been built using existing macro-magnitudes for Catalan counties and big cities. This reflects the interdependencies within the economy of the Catalan coastal counties in detail to derive higher-order effects.

One of the advantages of using a method based on an IO model is that it makes it possible to differentiate economic flows, including direct, indirect and induced effects, within the different spatial units, quantifying the spillover effect, which in the case of tourism is usually significant. Thus, the model makes it possible to identify not only this effect at the local level, but also how it is distributed throughout the territory. On the other hand, the use of an IO model requires the availability of good and detailed tourism and economic statistics, as is the case in this study. Obviously, when this type of information is not available (or not accessible), other methods such as multiple regression models become an alternative approach (e.g. Alexandrakis et al., 2015; Liu et al., 2019; Yong, 2021).

The adopted approach is complementary to other methods widely used in the literature to estimate the economic value of beaches, such as those based on travel costs, WTP, and contingency methods (e.g. Pendleton et al., 2011; Ariza et al., 2012; Parsons et al., 2013; Gopalakrishnan et al., 2016; Toimil et al., 2018; Enríquez and Bujosa-Bestard, 2020; Rodella et al., 2020).

This study is restricted to analysing the physical effects of climate change in terms of SLR-induced erosion. Other effects are also expected, such as temperature increase, which is a critical challenge faced by local authorities (March et al., 2014). In fact, most of the existing assessments of climate change on coastal tourism development have focused on climatic attractiveness (e.g. Amelung and Viner, 2006; Moreno and Amelung, 2009; Perry, 2006, among others). Therefore, the estimated impact of climate change on the economy is higher than that presented here.

In this work we have used the IPCC AR5 sea-level projections, which were available at the time of the analysis. These projections have now been updated in the IPCC AR6 (Fox-Kemper et al., 2021), and are slightly higher. For illustrative purposes, the RCP8.5 AR5 values for 2100 used here (0.74) would correspond to the SSP3-7.0 AR6 scenario, which gives for Barcelona in 2100 a sea level rise of 0.75 ± 0.27, and would also be within the values expected under SSP5-8.5 AR6 (0.85 ± 0.29) (Garner et al., 2021). At shorter time spans (2050, 2075), the differences between the RCP8.5 AR5 values used here with respect to the SSP5-8.5 AR6 are about 2.6 and 6 cm respectively. These relative low differences, especially up to 2075, together with the range of SLR values covered in this study (3 scenarios including H+), allow us to assume representativeness of the estimated impact of future conditions in the area.

5.2. Economic consequences on recreational areas along the Catalan coast

Tourism activities in 2019 generated approximately 7500 million € in the coastal counties of Catalonia (excluding Barcelonés), representing approximately 12.8% of the total GDP. These figures indicate that any variation in the development of this sector could have significant economic implications. In addition, spillover effects must also be considered, because when tourists buy a product from a local store or have a meal in a restaurant, the economic impact is not limited to the territorial unit but also includes the manufacturing area, which may be a remote area. Using the same IO model, these spillover effects were estimated at 4350 million euros, which are distributed among other areas of Catalonia, the rest of Spain and abroad. Therefore, the final contribution of tourism to the GDP exceeds the values obtained, because it strictly reflects the impact of tourism expenditures within individual counties.

Moreover, the impact on the economy quantified here is not the only effect. The predicted significant loss of jobs and activities generated would translate into a loss of population that would affect other productive sectors (e.g. public services, administration), and consequently, would generate a greater economic impact. The use of this type of predictive model becomes an essential tool to design appropriate policies for each territory, not only to preserve tourism but also to generate alternative activities that compensate for this reduction.

Although SLR is a threat affecting the entire region with relatively small spatial variations in the induced shoreline retreat, its impact on the beach surface and carrying capacity per county demonstrates a large spatial variability, which depends on the initial resource stock (beaches) per county (Fig. 4). When this is combined with the number of potential users per county, the spatial variability increases further, with two main areas appearing as the most potentially affected, the Costa Brava and Costa Daurada brands, with La Selva as the most impacted county (Fig. 5). This, together with the increased contribution of tourism to the local GDP, explains the large expected impact of SLR on the economy of the counties of these tourism brands (Fig. 8). Due to the projected changes in the SLR rate over time for the selected scenarios, as well as to their cumulative morphological effects, the expected impact on the local economy will significantly increase by 2075.

5.3. Management implications

Disaggregating the economic impact of SLR into regional accounts allows us to reflect the existing differences in the vulnerability of the tourism sector between counties, which could help in making decisions on the adoption of adaptation strategies to address the effects of climate change along the Catalan coast.

The analysis has identified areas with excess carrying capacity. These are usually composed of natural beaches with low density of use, such as those in the Ebro delta, which, theoretically, could accommodate users from other areas where beaches are insufficient to maintain the current level of use. However, this has different implications from a management point of view. Thus, if the redistribution of users is promoted, the receiving (e.g. deltaic) beaches will change their profile from low to high density of use, and it would also be necessary to increase the services and infrastructure offered in the area to accommodate the new users. All of this will mean an increase in pressure on the territory that would be incompatible with maintaining the natural values of these areas. It should be considered that this redistribution of users along the territory could be affected by the difference in beach characteristics (e.g. sediment, slope, berm height, Jiménez and Valdemoro, 2019) that would influence their preferences (e.g. Roca et al., 2008; Lozoya et al., 2014).

On the other hand, this strategy would imply "abandoning" well-stablished areas with local economies strongly linked to tourism (e.g. Costa Brava). In economic terms, this redistribution of users would imply that the economy of "exporting" areas (where beach carrying capacity decrease) will be severely affected, as estimated here, whereas areas receiving new users will be positively impacted. In this analysis, we have maintained the current profile of beach use over time, with the maximum number of users per county determined by the existing beach area and the corresponding saturation level. This allowed us to evaluate the expected economic impact in the business-as-usual scenario of maintaining the current situation if adaptation measures are not implemented.

The method presented here is a useful tool for planning adaptation throughout the territory since it permits to assess the economic consequences of decisions made. Thus, adaptation measures can be considered more economically feasible as long as their potential benefits outweigh the associated costs. If the benefits are quantified in terms of avoiding GDP losses, the counties where it would be most worthwhile to invest in adaptation would be La Selva and Baix Empordà in Costa Brava, Baix Camp and Tarragonès in Costa Daurada, and Maresme in Costa de Barcelona (Fig. 8).

In a period of reduced availability of public funds for coastal preservation and adaptation (e.g. López-Dóriga et al., 2020), it is crucial to identify where it will be worth investing the funds. Once the potential impact of SLR on the tourism economy has been regionally determined, it can be used to identify where the greatest benefits/returns are derived from implementing adaptation measures among the different counties. This can be done simply by normalising the GDP losses that will be avoided in each county with the length of beaches necessary to provide recreation services to sustain the tourism economy, that is, the extension of beaches within the county to be affected by SLR. This would make it possible to identify where the greatest benefits/returns on investment will be obtained for each km of beaches. This is illustrated in Fig. 10, where it can be clearly seen that the most profitable investment in adaptation to sustain the tourism-related economy at any time horizon and scenario should be obtained in La Selva, where the benefit per km of beaches is approximately four times the average for all coastal counties.

Because this type of analysis highlights where the investments in coastal adaptation are going to provide the largest benefits at the local scale, they can also be used to facilitate the involvement of private investments in coastal adaptation. Thus, this will permit the identification of whether the interests of private investors (those related to the local tourism industry) are aligned with those of the public stakeholders (administration to fund coastal protection projects), which will contribute to tackling this challenge through coastal adaptation (e.g. Bisaro and Hinkel, 2018). Furthermore, these expected differences in the benefits/returns from maintaining beaches could also be used to design other instruments, such as a tax/fiscal instrument that imposes the

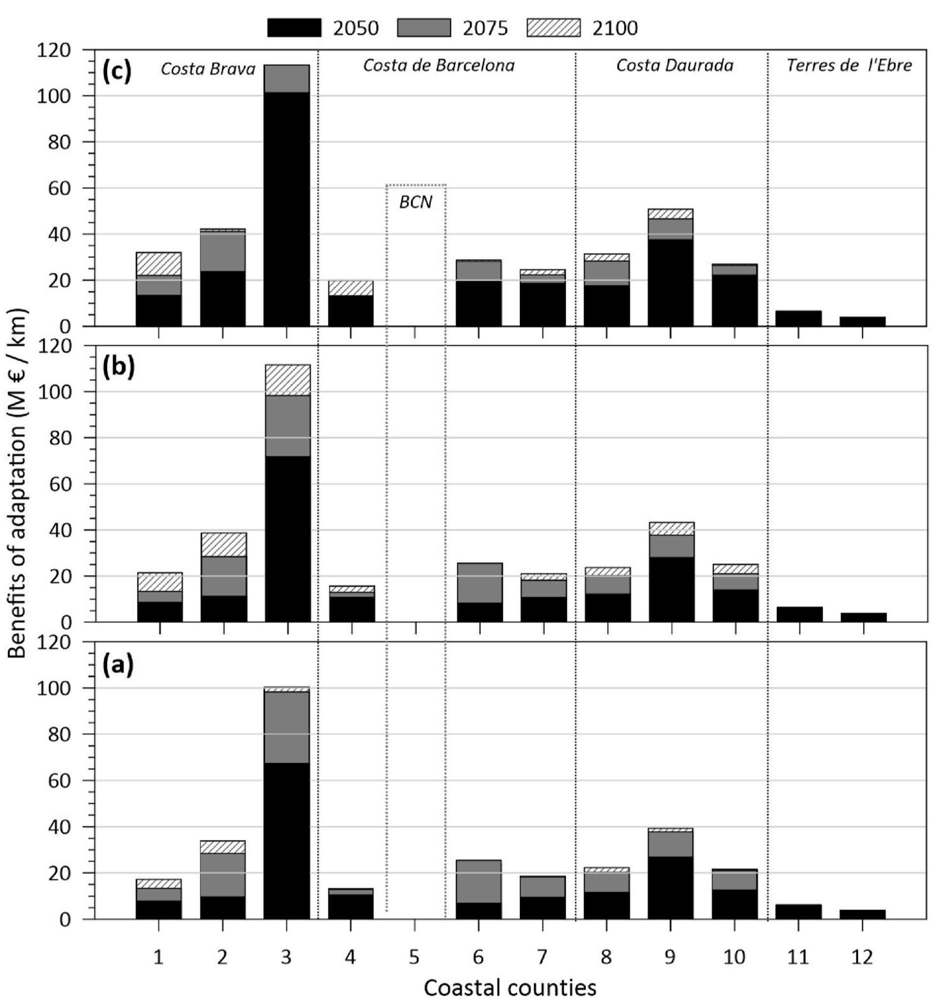

Fig. 10. The potential benefits of coastal adaptation for each county per km of beaches were measured as avoided tourism GDP losses under different climatic scenarios by 2050, 2075, and 2100. **(a):** RCP4.5; **(b):** RCP8.5; **(c):** H+.

highest cost on stakeholders who benefit the most from coastal adaptation (e.g. Mullin et al., 2019).

6. Conclusions

Sea level rise is expected to have a significant economic impact in coastal regions where sun-and-beach tourism is a dominant sector, as it will affect the main resource required for such activity, i.e. beaches. In this work, we have developed a methodological framework to assess the impact of SLR-induced erosion on tourism-related economy and applied it to the Catalan coast (NW Mediterranean).

The use of a regionalized county-scale IO model together with predictions of changes in beach carrying capacity integrated at the same scale has proven to be an efficient tool for assessing expected changes in GDP across the territory.

Concerning the analysed case study, the Catalan coast presents a high economic vulnerability to sea level rise, since tourism contribute 12.8% of the total GDP of coastal counties. The application of the framework for future SLR scenarios has also permitted to identify the most sensitive areas, which are coastal counties highly specialised in tourism, mostly concentrated in Costa Brava and Costa Daurada. The projected changes in total GDP for these counties under the RCP8.5 scenario range from approximately 16%–19% (by 2075) to 18%–26% (by 2100).

The framework also helps to make decisions on adopting adaptation strategies. Here, we propose normalising the GDP losses to be avoided with the length of beaches necessary to provide recreation services to identify the areas with the greatest benefits/returns on investment per km of beaches. For the case analysed, the greatest expected adaptation benefit for any time horizon and scenario should be obtained in La Selva, which will be approximately four times the average of all coastal municipalities. In any case, to make the final decision, this must be combined with the costs incurred in the adaptation, as well as factors other than economics.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was supported by the Spanish Ministry of Economy and Competitiveness (MINECO/AEI/FEDER, UE) in the framework of the M-CostAdapt project (CTM2017-83655-C2-1-R).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ocecoaman.2022.106034.

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