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Assessing social-ecological vulnerability of coastal systems to fishing and tourism

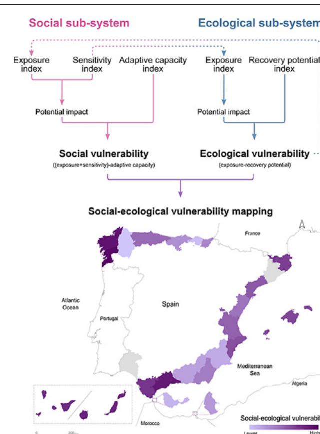
Natali Lazzari [a,*], Mikel A. Becerro [a], Jose A. Sanabria-Fernandez [a], Berta Martín-López [b]

[a] The BITES lab, Center for Advanced Studies of Blanes (CEAB-CSIC), Acc Cala S Francesc 14, 17300 Blanes (Gerona), Spain
[b] Leuphana University of Lüneburg, Faculty of Sustainability, Institute for Ethics and Transdisciplinary Sustainability Research, Universitätsallee 1, 21355 Lüneburg, Germany

HIGHLIGHTS

- We applied the social-ecological vulnerability (SEV) framework to fishing and tourism
- We spatially identified those temperate coastal areas with high and low SEV
- Those areas with a high dependency on one single industry were more likely to present higher SEV
- Livelihood diversification and the protection of marine areas may be strategies to build resilience
- Future research on SEV should consider extra pressures, e.g., agriculture and social-ecological interactions over distances

GRAPHICAL ABSTRACT



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ABSTRACT

Detecting areas with high social-ecological vulnerability (SEV) is essential to better inform management interventions for building resilience in coastal systems. The SEV framework, developed by the Intergovernmental Panel on Climate Change, is a robust method to identify SEV of tropical coastal systems to climate change. Yet, the application of this framework to temperate regions and other drivers of change remains underexplored. This study operationalizes the SEV framework to assess the social-ecological implications of fishing and tourism in temperate coastal systems. We spatially represented the SEV of coastal systems and identified the social and ecological vulnerability dimensions underpinning this SEV. Our results demonstrate that different dimensions contribute differently to the SEV, suggesting the need for distinctive management intervention to reduce the vulnerability of coastal systems. Our findings also highlight that livelihood diversification and the protection of marine areas may be plausible strategies to build resilience in temperate coastal systems that face fishing and tourism pressures. With this study, we hope to encourage the application of the SEV framework to other drivers of change for building more resilient coastal systems.

1. Introduction

Coastal marine systems (hereafter, coastal systems) are one of the most productive and biologically diverse systems of the planet (Agardy et al., 2005; Rogers et al., 2020). Coastal systems contribute to people's quality of life by supporting human livelihoods, regulating

* Corresponding author.
E-mail addresses: lazzari.natali@gmail.com (N. Lazzari), mikel.becerro@csic.es (M.A. Becerro), jsanabriafernandez@gmail.com (J.A. Sanabria-Fernandez), martinlo@leuphana.de (B. Martín-López).

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natural hazards, and providing cultural, spiritual, and aesthetics values (Agardy et al., 2005). Yet, as a result of the cumulative impact of anthropogenic activities, coastal systems are increasingly becoming socially and ecologically vulnerable (Agardy et al., 2005; Halpern et al., 2008).

The vulnerability term has been originally shaped by social disciplines but rapidly adapted to environmental change studies (Miller et al., 2010). With the increasing need to investigate the whole social-ecological systems as dynamic systems, the vulnerability framework became a useful tool for assessing the social-ecological vulnerability, especially when the empirical data constitute a single snapshot in time (Adger, 2006; Mumby et al., 2014). Social-ecological vulnerability (SEV) can be defined as the magnitude at which systems are unable to cope with disturbances, which affects the systems' social and ecological systems (Adger, 2006; Cinner et al., 2012). The vulnerability framework, formalized and promoted by the Intergovernmental Panel on Climate Change (IPCC), has proven to be a robust method for understanding the coastal system's responses to climate change (IPCC, 2007; Marshall et al., 2009; Thiault et al., 2017). Its operationalization has been realized through assessments of SEV to climate change in tropical regions (e.g., Cinner et al., 2013; Siegel et al., 2019). As a result, the majority of management policies and programs aiming to reduce the vulnerability of coastal systems have mainly focused on mitigating climate change effects (Bennett et al., 2016). Yet, climate change is only one of the drivers of change causing coastal degradation (Agardy et al., 2005; Díaz et al., 2015). Other drivers of change, such as habitat alteration, overexploitation, and pollution affect coastal and marine biodiversity to a higher extent than climate change (Pereira et al., 2012; Rogers et al., 2020). Those multiple drivers of change stem from industries that rely on coastal systems such as fishing and tourism. Despite the critical role of assessing the capacity of coastal systems to cope with multiple disturbances plays when designing management actions, the operationalization of the SEV framework to drivers other than climate change remains a challenge (Thiault et al., 2017; Abelson, 2019).

Coastal systems nurture the fishing and tourism industries (Agardy et al., 2005; Bennett, 2019). Coastal artisanal fisheries, i.e., fisheries using vessels under 12 m in length (Quetglas et al., 2016; Villasante et al., 2016), represent 90% of the world's fishing fleet and fishers. Coastal systems are also important tourist destinations. About 50% of tourists spend time at the coastline and conducting recreational activities such as SCUBA diving, windsurfing, and recreational fishing (Orams, 1998; United Nations, 2017). In Spain, fishing and tourism highly contribute to the economic development of the country (Dirección General de Sostenibilidad de la Costa y del Mar, 2008; Losada et al., 2014). The high contribution of both activities to the economic development of Spain has been at the expense of preserving coastal and marine biodiversity. For example, the Spanish Millennium Ecosystem Assessment reported that coastal systems are the most degraded habitat in Spain (Spanish MEA, 2011). The Spanish Millennium Ecosystem Assessment also concluded that overexploitation of fisheries, urbanization, and climate change are the most important stressors in the Spanish coastal systems (Spanish MEA, 2011). Certain activities associated with fishing and tourism may turn coastal systems into highly vulnerable areas in Spain. Assessing the SEV of coastal systems may help identify those areas that need urgent intervention and point to proper management actions. For example, identifying areas with low/medium vulnerability may suggest actions to mitigate the future impacts of fishing and tourism while restoration programs may be more adequate in highly vulnerable areas.

In this study, we aim to operationalize the SEV framework in temperate coastal systems where tourism and fishing activities are important stressors of marine biodiversity. First, we assessed the capacity of the coastal marine social-ecological system to cope with the pressures derived from fishing and tourism in the Spanish coastal systems. Second, we mapped SEV hotspots, detecting areas of high social and ecological vulnerability. And third, we identified the key social and ecological dimensions underpinning vulnerability.

2. Study area

We applied the SEV framework to the Spanish coastal system, which encompasses almost 6600 km-long distributed along five Marine Ecoregions of the World: i) South European Atlantic Shelf, ii) Azores Canaries Madeira, iii) Saharan Upwelling, iv) Alboran Sea, and v) Western Mediterranean (Fig. 1). The diverse biophysical characteristics of the Spanish coastal system, such as the irregular underwater geography or upwelling areas, foster a wide variety of marine ecosystems with high biodiversity (Yepes and Medina, 2005; Coll et al., 2010). The Azores Canaries Madeira ecoregion is considered a transition zone where both sub-tropical and temperate marine species coexist (Brito et al., 2001; Tuya and Haroun, 2009; Freitas et al., 2019); the Western Mediterranean and the Alboran Sea ecoregions are located in the Mediterranean sea, which hosts one of the world's hotspots of marine biodiversity (Myers et al., 2000; Coll et al., 2010), and the South European Atlantic Shelf is one of the most productive areas of Spain (Ministerio de Medio Ambiente y Medio Rural y Marino, 2008).

In terms of the socio-economic characteristics, coastal provinces represent 31% of the total surface of Spain and host 60% of the Spanish population. The coastal system hosts a wide variety of human activities such as fishing and tourism. The Spanish economy depends largely on these two activities. Fishing in Spain provides more than 30,000 direct jobs and yields a landing over 900,000 tons of fish per year, being the European country with the highest fish production (Confederación Española de Pesca, 2019). Tourism in the Spanish coastal systems provides 2.5 millions of direct jobs and, approximately, 90% of nights spent in tourism facilities in Spain occur in coastal areas (Eurostat, 2019).

3. Methods

3.1. Methodological framework

To evaluate the SEV (social-ecological vulnerability) to fishing and tourism in coastal systems we adapted the vulnerability framework originally designed for climate change assessments (Marshall et al., 2009; Fig. 2). We defined the SEV as the magnitude to which a coastal system, including both social and ecological components, is susceptible to and unable to cope with the pressures caused by fishing and tourism activities (Adger, 2006; Marshall et al., 2009). The *exposure*, *sensitivity*, and *adaptive capacity* are the elements of vulnerability, where the *exposure* and *sensitivity* to external pressures result in social and ecological potential impacts, and the *adaptive capacity* of the systems is the ability to cope with such impacts (Adger, 2006; Marshall et al., 2009; Fig. 2). See Table S1 of Supplementary Material for additional information.

Exposure refers to the extent to which a region experiences social or ecological stress (Cinner et al., 2013). In the context of our study, we defined *social exposure* as the magnitude by which fishing and tourism areas are potentially exposed to ecological vulnerability (Fig. 2). We defined *Ecological exposure* as the magnitude of fishing and tourism pressures to which the ecological dimension is exposed (Fig. 2). For instance, in rocky reef ecosystems, exposure to high fishing pressures may lead to biodiversity loss and changes in the trophic chain (Maureaud et al., 2017), whereas the exposure to a high density of SCUBA divers may be a driver of habitat destruction (Giglio et al., 2020).

We defined *sensitivity* as the set of conditions and characteristics that mediate the propensity of a particular region to be influenced by fishing and tourism pressures (adapted from Bousquet et al., 2015). Therefore, *social sensitivity* in this study refers to the degree by which people depend on fishing and tourism (Fig. 2), whereas *ecological sensitivity* is the degree to which an ecological system is affected by fishing and tourism pressures (Marshall et al., 2009). For example, social systems are more sensitive to ecological changes if they are highly dependent on a vulnerable natural resource (Cinner et al., 2013).

Finally, *adaptive capacity* captures the ability to respond and to address social and ecological changes by mitigating, coping with, and

Fig. 1. Map of the study area showing the geographical location of the Spanish coastal provinces sampled (grey polygons), and biological sampling sites (blue circles). Dashed lines represent the limits of marine ecoregions: (i) South European Atlantic Shelf, (ii) Azores Canaries Madeira, (iii) Saharan Upwelling, (iv) Alboran Sea, and (v) Western Mediterranean. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

recovering from the potential impact caused by a particular pressure (Thiault et al., 2019a). Here, we defined the *social adaptive capacity* as the set of demographical, economic, and mobility characteristics that enhance people's ability to mitigate, cope, and recover from the potential impacts caused by fishing and tourism (Fig. 2). For example, high *social adaptive capacity* may promote people's ability to adapt to changes in fishing and tourism or to take advantage of the opportunities created by these changes (Cinner et al., 2013). Since the *ecological adaptive capacity* also depends on inherent characteristics of the ecological community, in this study, we integrated *ecological sensitivity* and *ecological adaptive capacity* under the umbrella of the so-called *recovery potential* (Cinner et al., 2013; Thiault et al., 2017). Therefore, *recovery potential* refers to those characteristics of the ecological community that mediate the capacity of the ecosystem to respond to fishing and tourism pressures (Fig. 2).

In the SEV framework operationalized in this study, the social and ecological systems are intrinsically linked, leading to the co-dependency of both systems. In this depiction of the SEV, the social system connects with the ecological system through the ecological vulnerability, which defines the social exposure, whereas the ecological system connects with the social system through the social sensitivity, which contributes to the exposure of the ecological system (Marshall et al., 2013; Thiault et al., 2017; Fig. 2).

3.2. Methodological approach

3.2.1. Data collection

To assess the SEV to fishing and tourism in Spanish coastal systems, we collected relevant information on ecological and socio-economic systems (Table S2). To calculate the *recovery potential*, we collected data on the fish community inhabiting littoral rocky reefs of the Spanish coastline (Table S2). We focused our study on the fish community because fish represent an important tourist attraction, are a major protein source for humans and are highly affected by human activities such as coastal development or natural resources exploitation (Agardy et al., 2005; Halpern et al., 2008). We collected fish abundance data from 291 sampling sites scattered along the Spanish coastline following the standard Reef Life Survey (RLS) protocol (Edgar and Stuart-smith, 2014). Each sampling site, distanced from others by at least 200 m, represented one or more transects parallels to the coastline (average of 1.8 transects per site). Using the RLS underwater visual census, we estimated the abundance of each fish species sighted along a 50 m long, 5 m wide belt transect (total surface sampled = 250 m^2) (Edgar and Stuart-smith, 2014; Edgar et al., 2020). For more details of the standardized RLS survey procedures check the online methods manual (https://reeflifesurvey.com/wp-content/uploads/2015/07/NEW-Methods-Manual_150815.pdf).

We used the biological information collected through RLS to build three variables that were used to calculate *recovery potential:* i.e. species richness, functional redundancy, and resilience to fishing (Table S2). Species richness informs about the fish community productivity and recruitment facilitation (Bernhardt and Leslie, 2013; Cinner et al., 2013), functional redundancy informs about the pool of functional traits available in the community (Bernhardt and Leslie, 2013; Cinner et al., 2013), and resilience to fishing provide information about those intrinsic characteristics that make the fish community more or less susceptible to fishing pressures (Cheung et al., 2005; Thiault et al., 2017). We calculated species richness as the average of the total number of fish species per sampling site. To estimate species richness, we used the diversity function of the 'vegan' R package (Oksanen et al., 2018). To estimate functional redundancy, we used five relevant functional traits of fish that provide information on key physiological, behavioral, and

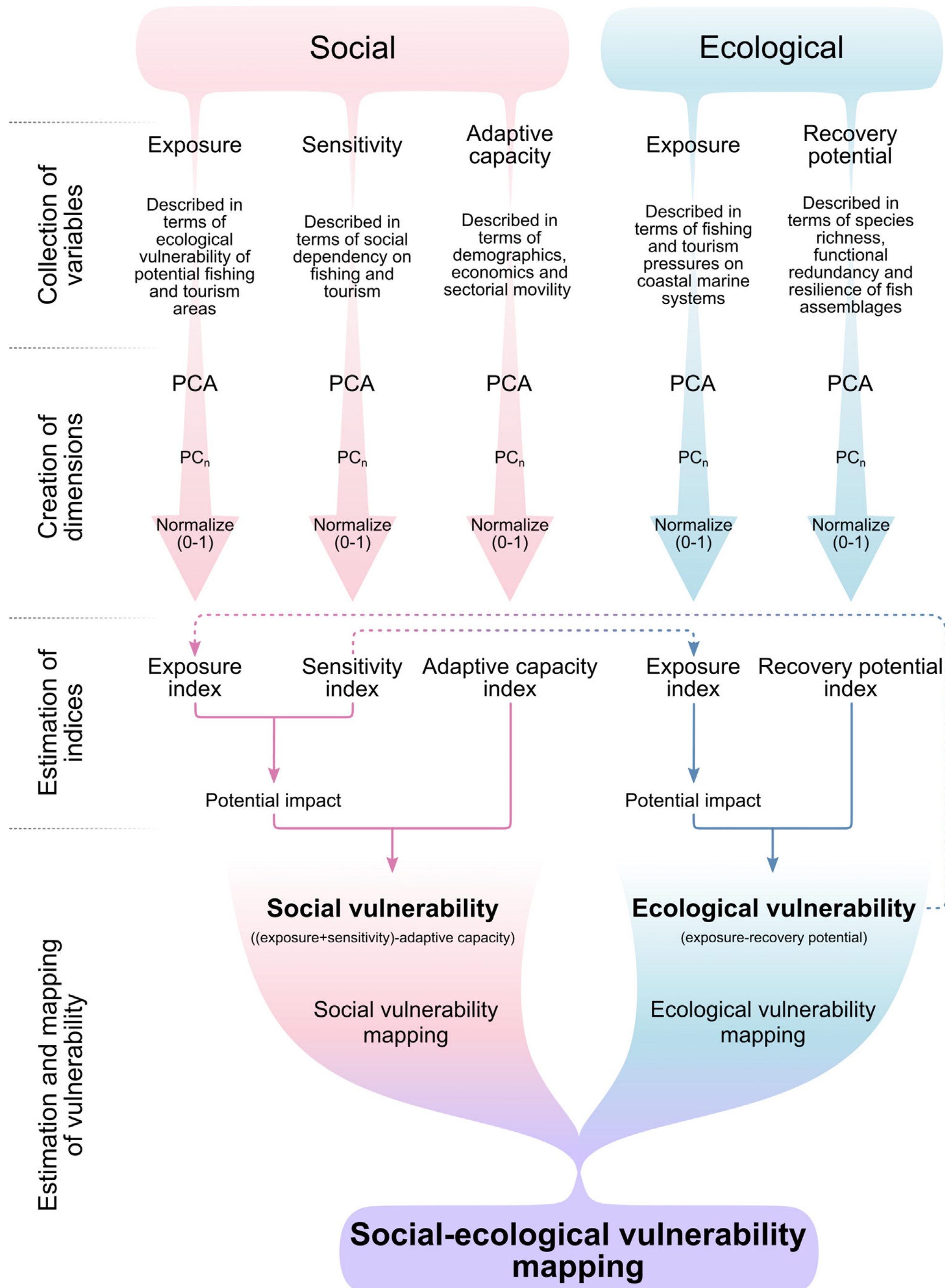

Fig. 2. Methodological approach used to operationalize the social-ecological vulnerability framework in the Spanish coastal system. We represented the co-dependency of social and ecological systems by dashed lines. By applying principal component analysis, we unveiled the dominant relationships between variables that define different dimensions. Then, we combined the dimensions into single and un-weighted indices of social and ecological exposure, sensitivity, adaptive capacity, and recovery potential. Finally, we applied an additive approach to estimate social, ecological, and social-ecological vulnerabilities.

environmental aspects (i.e. maximum length, trophic group, water column position, habitat complexity, and gregariousness) (Stuart-Smith et al., 2013). We obtained traits information from FishBase (www.fishbase.org; Froese and Pauly, 2000) and Stuart-Smith et al. (2013). Then, we used the dbFD function of the 'FD' R package (Laliberté and Legendre, 2010) to quantify the Rao's quadratic entropy (RaoQ) used as a measure of functional redundancy (Botta-Dukát, 2005). Finally, we estimated the resilience to fishing, such as the ability of fish species to recover from fishing pressures. We defined resilience to fishing as the opposite of the intrinsic vulnerability index developed by Cheung et al. (2005). For each fish species, we estimated the resilience to fishing weighted by their abundance, then we used the community-weighted mean as the resilience to fishing variable (Thiault et al., 2017; Table S2). Those communities with a higher number of species and functions, and with intrinsic characteristics that make them less vulnerable to fishing, such as lower maximum length, early age at first maturity, or wide geographic range, increase their recovery potential to fishing and tourism pressures (Cheung et al., 2005; Cinner et al., 2013). We focused our study area on those coastal provinces where large rocky bottom habitats are present. These areas span all over the Spanish litoral, including the mainland, the main islands, and small territories of the Mediterranean coast of North Africa ("Santa Cruz de Tenerife", "Las Palmas", Balearic Islands, "Ceuta", "Melilla", "Gerona", "Tarragona", Castellon, "Valencia", "Alicante", "Murcia", Almeria, "Granada", Malaga, Cadiz, "Pontevedra", "La Coruña", "Lugo", "Asturias", "Cantabria", Biscay, and Guipuzcoa, Fig. 1). To calculate the social indices of *sensitivity* and *adaptive capacity*, we collected socio-economic information on the fishing and tourism industries. The index of *social sensitivity* included information from five different variables (Table S2): fish consumption (percentage of annual fish consumption), level of employment in fishing and hotel industries (percentage of contracts on fishing and hotel industries), tourist accommodation (number of hotel rooms), and tourist room profit (profit in euros per tourist room by day). The index of *social adaptive capacity* included information from five variables (Table S2): literacy (inhabitants with elementary school or a higher education level), multidimensional wealth (based on the income distribution and consumption patterns), unidimensional wealth (based on the family capacity to live between consecutive wages without difficulties), and mobility in the primary (number of contracts in agriculture and fishing industries that involve interprovincial displacement) and tertiary (number of contracts in a service industry that involves interprovincial displacement) sectors. Besides, we also used socio-economic information to calculate *ecological exposure. Ecological exposure* included eight variables (Table S2): fishing vessels (number of artisanal fishing vessels per km of coastline), fishing vessel gross tonnage (volume capacity of all artisanal fishing vessels per km of coastline), fish landings (tons per km of coastline of littoral fish extracted), recreational fishing and underwater activities licenses (number of fishing licenses and underwater activities licenses per km of coastline), recreational vessels registration (number of new recreational vessels registered per km of coastline), dive centers (number of dive centers per km of coastline) and tourism (number of tourists per km^2). All socio-economic data came from several national and international public databases: Spanish Statistical Office, Public Service State Employment, Ministry of Agriculture, Fisheries and Food, The Food and Agriculture Organization, Superior Sports Council, National Association of Nautical Companies (Table S2).

Finally, we used two variables to calculate *social exposure*: the fishing industry exposure, understood as the average ecological vulnerability of the potential fishing area, and the tourism industry exposure, understood as the average ecological vulnerability of the potential tourism area. Because artisanal fisheries in Spain operate with artisanal vessels in an area close to the port of departure, we estimated the fishing industry exposure as the average ecological vulnerability within a buffer area of 12 nautical miles from each Spanish port with artisanal fisheries (Soltanpour et al., 2017). The distance traveled by tourists varies with location but, in general, the number of visitors to recreation sites decreases with distance (Alves et al., 2017). Tourists' mobility in southern Spain ranges between 20 and 300 km (Martín-López et al., 2009), so we assumed an average displacement of 100 km. To estimate the tourism industry exposure, we measured the average ecological vulnerability within a buffer area of 100 km from the geographical center of each coastal municipality.

3.2.2. From variables to vulnerability indices and maps

To calculate the indices of *social* and *ecological exposure, sensitivity, adaptive capacity,* and *recovery potential* for both fishing and tourism pressures, we separately conducted five principal component analysis (PCA, one for each index) to unveil the dominant relationships between variables that define different dimensions (see Section 3.2.1.; Fig. 2). When using equal weights combination of variables highly correlated, the PCA avoid the introduction of double-counting elements into the indices (OECD, 2008). We used varimax rotation in some indices to facilitate the interpretation. We assumed that the principal components (PCs) obtained through the PCAs represent different dimensions of *social* and *ecological exposure, sensitivity, adaptive capacity,* and *recovery potential.* We finally performed a Pearson correlation test to assess the independence of the dimensions.

Before computing the PCAs, all variables were log-transformed (x + 1) and scaled to avoid heteroscedasticity. To test the suitability of the data for PCA, we used Kaiser- Meyer-Olkin (KMO) and Bartlett's tests. KMO is a measure of sampling adequacy that indicates the proportion of common variance. Bartlett's test indicates whether the correlation matrix is an identity matrix or not, which indicates whether variables are unrelated. Values of KMO higher than 0.5 and significant Bartlett's test ($p < 0.05$) indicate that the data might be suitable for PCA.

In each of the five PCA, we retained those PCs with an eigenvalue larger than 1 (Kaiser, 1960). The factor loadings of the retained PCs informed about the different coherent dimensions that explain *social* and *ecological exposure, sensitivity, adaptive capacity,* and *recovery potential*. After rescaling the dimensions between 0 (lowest value) and 1 (higher value), we combined them into single and un-weighted indices of *social* and *ecological exposure, sensitivity, adaptive capacity,* and *recovery potential* (Fig. 2).

To estimate the social, ecological, and social-ecological vulnerability we applied an additive approach among indices, which assumed that all the indices had equal importance. We rescaled the indices between 0 and 1 previous to the estimation of social and ecological vulnerabilities. As presented in Fig. 2, we calculated the social vulnerability as (exposure + sensitivity) - adaptive capacity; we estimated the ecological vulnerability as exposure - recovery potential; and we calculated SEV as social vulnerability + ecological vulnerability (Thiault et al., 2017). Before estimating SEV, we rescaled the ecological and social vulnerabilities between 0 and 1.

Finally, to visualize spatial differences in social, ecological and social-ecological vulnerability to fishing and tourism in Spain, we mapped the social, ecological, and social-ecological vulnerability of the Spanish coastal provinces using the Free and Open Source Geographic Information System QGIS (QGIS Development Team, 2019). Besides, we created scatter-plots to graphically represent the *recovery potential* and the *social adaptive capacity* against the pressure from tourism and fishing activities. We also presented in a scatter-plot the existing SEV to tourism and fishing. Then, we conducted a PCA to unveil the multivariate relationships among the ecological and social vulnerability dimensions and the coastal provinces in Spain. We used R software (R Core Team, 2018) to conduct all the statistical analyses and graphical representations.

4. Results

4.1. Creating the dimensions of vulnerability indices

We found eight social-ecological dimensions for *social* and *ecological exposure, sensitivity, adaptive capacity,* and *recovery potential* for both fishing and tourism: exposure of the social system to ecological vulnerability, dependency on fishing, dependency on tourism, adaptive capacity of the social system, fishing pressure, pressure from local recreational activities, pressure from non-local recreational activities, and recovery potential of the fish community (Fig. 3). All the dimensions identified presented a Pearson correlation coefficient lower than 0.65. First, *social exposure* was represented by the first PC (98% of variance), which indicated the exposure of the social system to ecological vulnerability. PC1-Exposure of the social system to ecological vulnerability presented in its positive loads the variables fishing industry and tourism industry exposure (Table S3). Second, for *social sensitivity,* we retained the first two rotated PCs, which explained 87% of the variance: PC1 (48% of variance) and PC2 (39% of variance) (Table S3). PC1-Dependency on tourism included tourist accommodation, tourist room profit, and employment in the hotel industry. PC2-Dependency on fishing included fish consumption and employment in the fishing industry in its positive loads (Table S3). Third, we retained the first PC (68% of variance) to represent *social adaptive capacity*. PC1-Adaptive capacity of the social system included all the variables considered for *social adaptive capacity:* multidimensional wealth, unidimensional wealth, literacy, mobility in the primary sector, and mobility in the tertiary sector (Table S3).

Fourth, for *ecological exposure,* we retained the first three rotated PCs that explain 79% of the variance (Table S3). PC1-Fishing pressure (31%

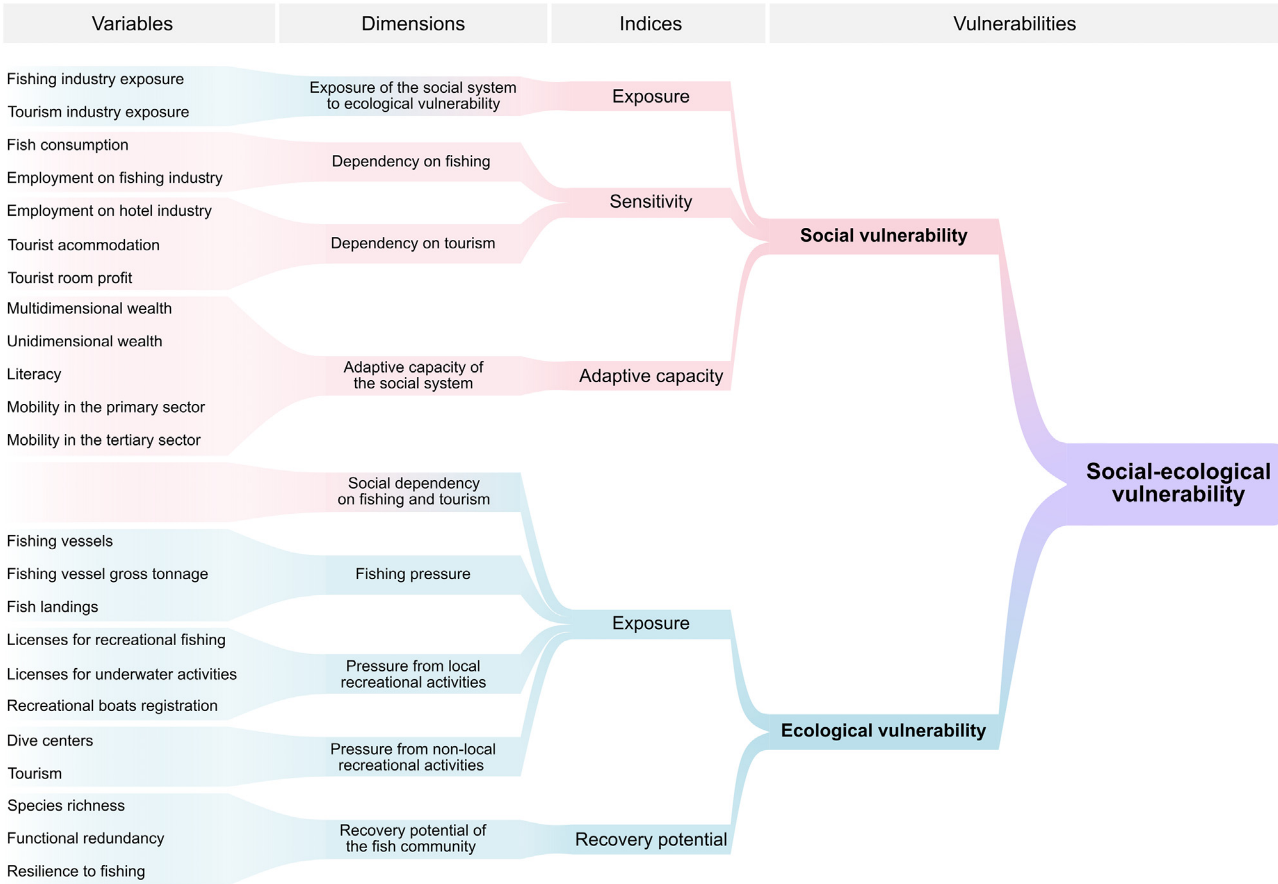

Fig. 3. Relation of the terms used to appoint the variables, dimensions, indices, and vulnerabilities.

of variance) included the variables of fishing vessels, fishing vessel gross tonnage, and fish landings. PC2-Pressure from local recreational activities (31% of variance) included licenses for recreational fishing, licenses for underwater activities, and recreational boat registration. PC3-Pressure from non-local recreational activities (18% of variance) included the dive centers and tourism (Table S3). Finally, we retained the first PC-Recovery potential of the fish community (54% of variance) that included species richness, functional redundancy, and resilience to fishing (Table S3).

4.2. Social vulnerability

For social vulnerability, we calculate three indices: *social exposure, social sensitivity,* and *social adaptive capacity* (Fig. 3). *Social exposure* and *adaptive capacity* were estimated through the dimensions of exposure of the social system to ecological vulnerability and adaptive capacity of the social system, respectively. We calculated *social sensitivity* through the dimensions of dependency on fishing and dependency on tourism.

The highest and the lowest social vulnerability was found in the Atlantic region, in “Pontevedra” and Biscay, respectively (Fig. 4a). Nearly half of the Atlantic provinces presented high social vulnerability, whereas 33% of the Atlantic provinces presented low social vulnerability. The Mediterranean region presented an even distribution of high and low social vulnerability, with 23% of the region belonging to both cases. In the Mediterranean region, Malaga and Cadiz had the highest ecological vulnerability, while “Ceuta” and “Melilla” had the lowest.

Balearic Islands, “Santa Cruz de Tenerife”, and “Las Palmas” presented a higher dependency on tourism (Fig. 4b), whereas the provinces of “Pontevedra” and “La Coruña” had the highest dependency on fishing (Fig. 4c).

4.3. Ecological vulnerability

For ecological vulnerability, we calculated two indices: *ecological exposure* and *recovery potential* (Fig. 3). *Ecological exposure* included three ecological dimensions (fishing pressure, pressure from local recreational activities, and pressure from non-local recreational activities) and two social dimensions (dependency on fishing and dependency on tourism) (Fig. 3). We estimated *recovery potential* with the dimension of the recovery potential of the fish community (Fig. 3).

We found that the Atlantic region presented 22% of its coastal system with high ecological vulnerability and 33% with low ecological vulnerability (Fig. 5a). The highest ecological vulnerability in the Atlantic region lies in “Pontevedra” and “La Coruña”, while the lowest lies in “Lugo” and Biscay. The Mediterranean region presented 15% and 32% of its coastal system with high and low ecological vulnerability, respectively (Fig. 5a). In the Mediterranean region, we found that “Gerona” had the highest ecological vulnerability, followed by “Alicante”, Malaga, and “Tarragona”.

Whereas the Mediterranean provinces of “Gerona”, “Alicante”, “Melilla”, Balearic Islands, and Malaga withstood higher pressure from recreational activities (Fig. 5b), the Atlantic provinces of “Pontevedra” and “La Coruña” withstood the highest pressure from fishing activities (Fig. 5c).

4.4. Social-ecological vulnerability (SEV)

Overall, we found that 44% of the Atlantic Region and 23% of the Mediterranean Region had high levels of SEV. We found that the coastal system with the highest SEV was located in “Pontevedra” and “La Coruña”, in the Atlantic Region, followed by Malaga in the

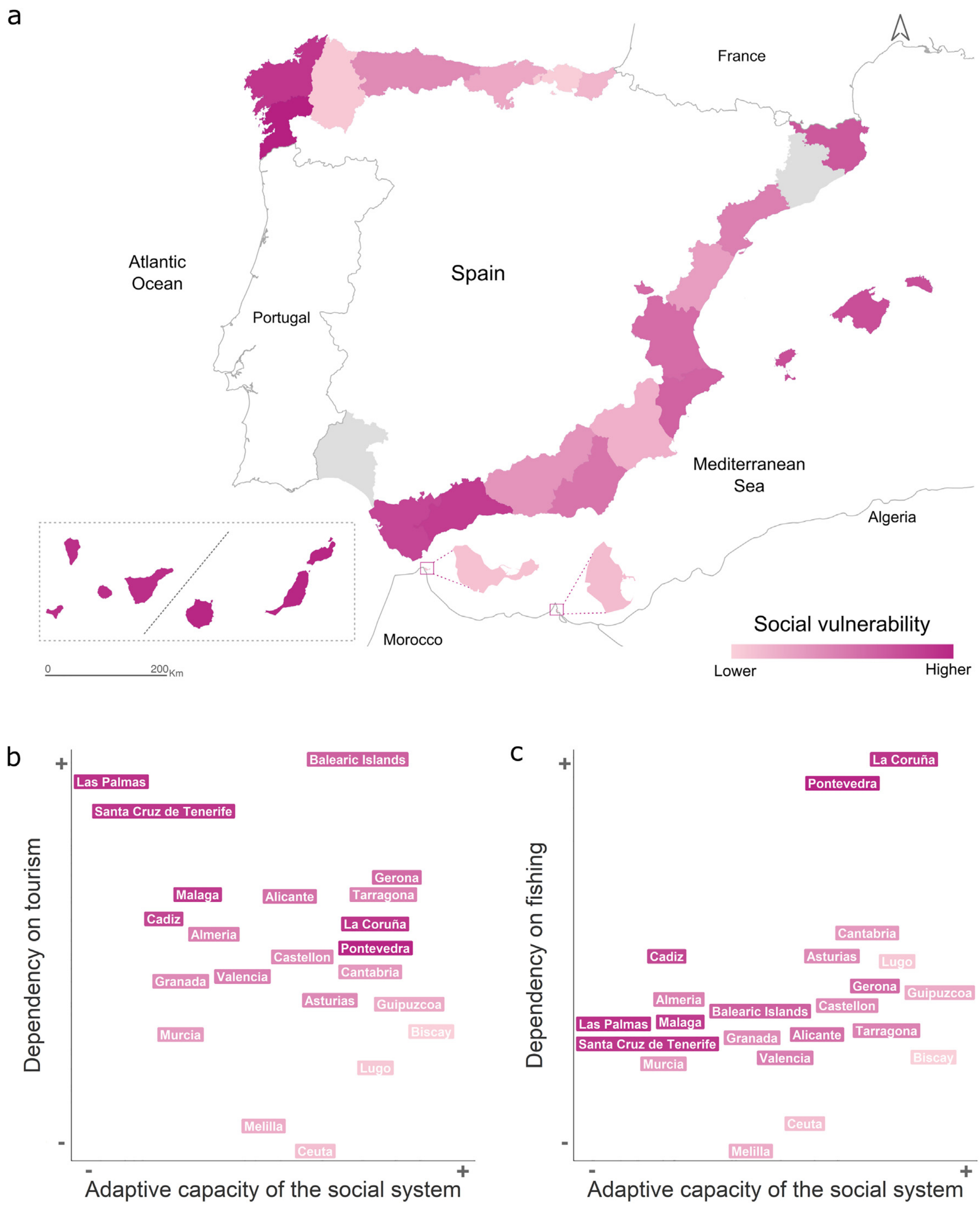

Fig. 4. Social vulnerability of Spanish coastal provinces to dependencies on tourism and fishing. (a) Map of spatial variation of social vulnerability. Breakdown of social vulnerability according to the (b) dependency on tourism and (c) dependency on fishing. Both indicators were represented against adaptive capacity of the social system. The color gradient from light pink to dark pink shows the gradient from lower to higher social vulnerability. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Mediterranean Region (Fig. 6a). While the high SEV of "Las Palmas", "Santa Cruz de Tenerife", and "Gerona" was related to their vulnerability to tourism, the high SEV of "Pontevedra" and "La Coruña" was associated with their vulnerability to fishing. Malaga and Cadiz presented intermediate values of both social-ecological vulnerabilities to tourism and fishing (Fig. 6b).

The first two axes of the PCA explained 58.6% of the variation among the social and ecological vulnerability dimensions across provinces (Fig. 7). Positive scores of PC1 (33.8% of variance) represented those areas with higher pressure from fishing, dependency on fishing, exposure of the social system to ecological vulnerability (i.e., "Pontevedra" and "La Coruña"), and with a higher adaptive capacity of the social system ("Asturias" and Guipuzcoa). Conversely, negative scores of PC1 represented those provinces with higher pressure from non-local recreational activities (Balearic Islands, "Santa Cruz de Tenerife", and "Las Palmas") and recovery potential of the fish community. PC2 (24.8% of variance) represented those areas with a higher dependency on tourism (Balearic Islands,

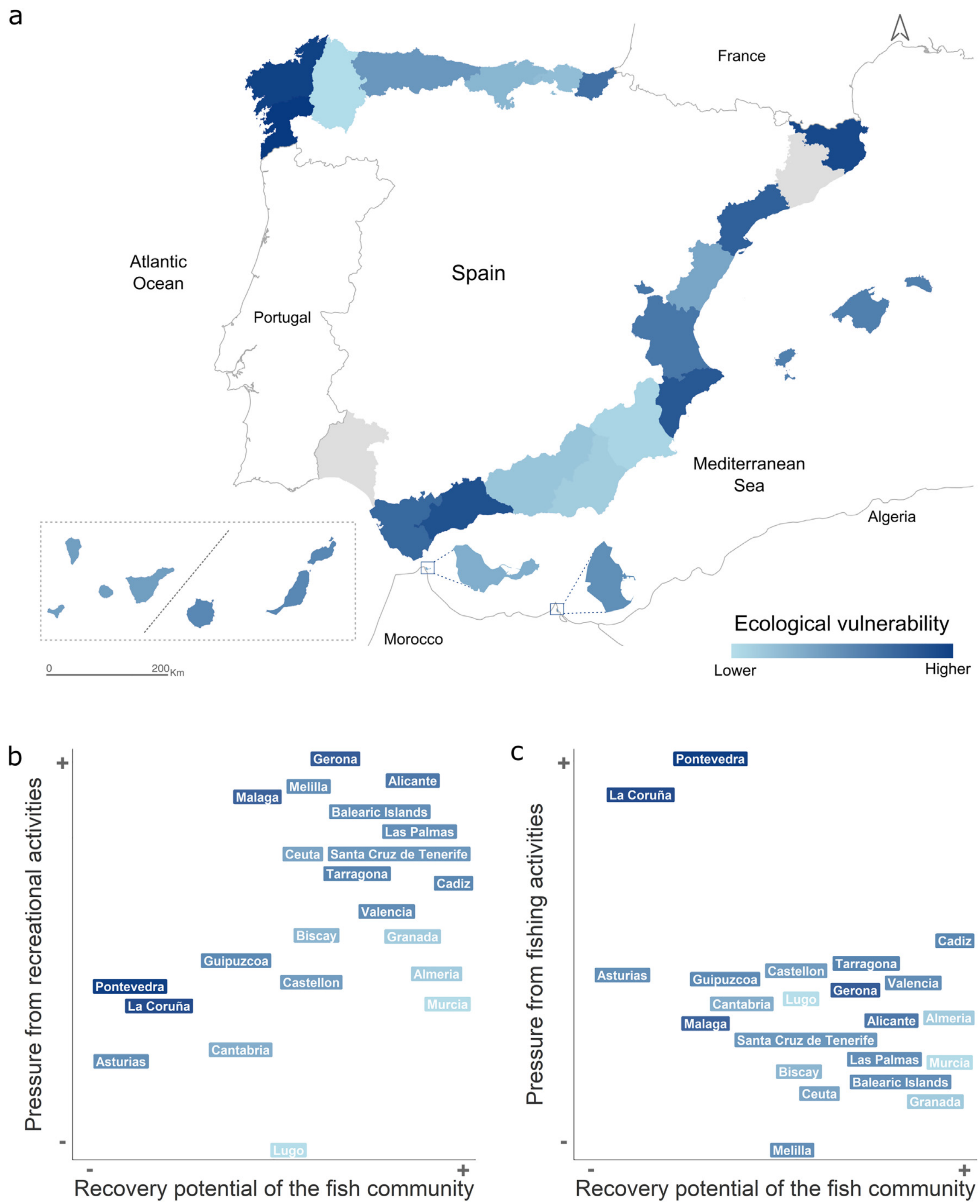

Fig. 5. Ecological vulnerability of Spanish coastal provinces to tourism and fishing pressures. (a) Map of spatial variation of ecological vulnerability. Breakdown of ecological vulnerability according to (b) pressure from recreational activities and (c) pressure from fishing activities. Both indicators were represented against the recovery potential of fish community. The color gradient from light blue to dark blue shows the gradient from lower to higher ecological vulnerability. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

"Santa Cruz de Tenerife", and "Las Palmas"). Negative scores of PC2 represented those provinces with higher pressure from local recreational activities (Biscay and "Lugo") (Fig. 7). The provinces with high SEV were differently associated with tourism and fishing. For example, "Pontevedra" and "La Coruña" were related to higher dependency on fishing, fishing pressure, and exposure of the social system to ecological vulnerability. "Las Palmas" and "Santa Cruz de Tenerife" were related to higher dependency on tourism and pressure from non-local recreational activities (Fig. 7).

5. Discussion

To identify the areas that should be prioritized for management actions that foster resilience has become essential to mitigate and adapt to changes in the Anthropocene (Thiault et al., 2017). By assessing the SEV of temperate coastal systems to multiple pressures, we can identify areas with less capacity to cope with disturbances and where urgent management interventions are needed to build resilience (Adger, 2006). Our results demonstrate that different dimensions contribute to SEV,

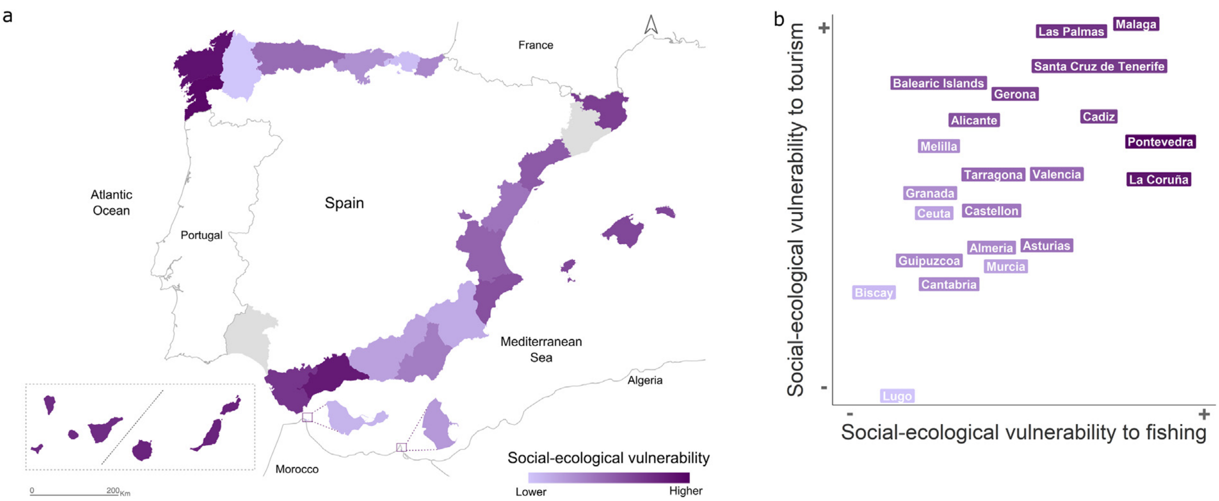

Fig. 6. Social-ecological vulnerability of Spanish coastal provinces to tourism and fishing. (a) Map of spatial variation of social-ecological vulnerability. (b) Scatter plot representing the social-ecological vulnerability to tourism against social-ecological vulnerability to fishing. The color gradient from light violet to dark violet shows the gradient from lower to higher social-ecological vulnerability. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

highlighting the need for distinctive management interventions in order to conserve and build resilience of coastal systems in temperate regions.

5.1. Advancing the operationalization of the SEV framework in temperate coastal systems for fishing and tourism

Our results demonstrated that the SEV framework, which was originally designed for climate change, can be operationalized to assess the vulnerability to other drivers of change such as fishing and tourism. To our best knowledge, this is an innovative application since most of SEV research in coastal systems have focused on tropical systems and climate change (Allison et al., 2009; Morzaria-Luna et al., 2014; Bennett et al., 2016). The emphasis on tropical systems and climate change has responded to the emergency to halt biodiversity loss in these important hotspots of species richness (Partelow et al., 2017). However, recent studies demonstrate that temperate regions are hotspots of functional diversity (Stuart-Smith et al., 2013) and, as such, they also require scientific attention to foster their conservation. Our study advances the understanding of the SEV in temperate regions to build resilience in these areas.

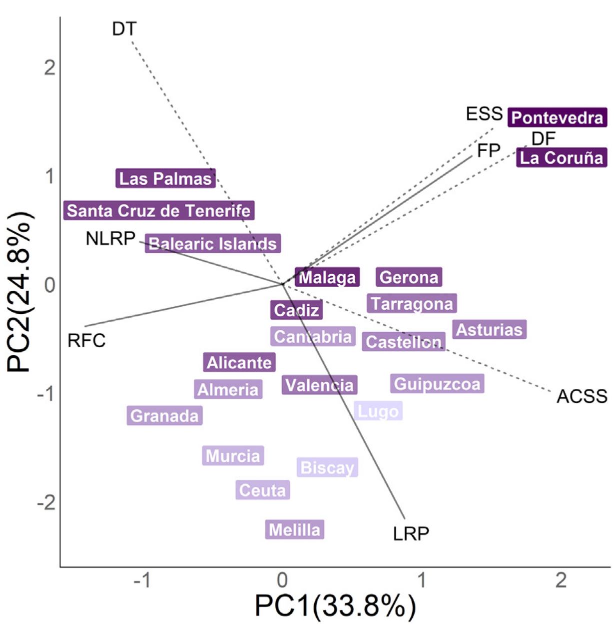

Fig. 7. Principal component analysis of the four social (grey dashed lines) and four ecological (grey solid lines) vulnerability dimensions: Adaptive Capacity of the Social System (ACSS), Dependency on fishing (DF), Dependency on tourism (DT), Exposure of the Social System to ecological vulnerability (ESS), Fishing pressure (FP), Pressure from Local Recreational activities (LRP), Pressure from Non-Local Recreational activities (NLRP) and Recovery potential of the Fish Community (RFC). The color gradient from light violet to dark violet shows the gradient from lower to higher SEV. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

We identified the SEV of temperate coastal systems to fishing and tourism pressures and unraveled the key social and ecological dimensions underpinning this vulnerability. First, we have extended the application of SEV beyond tropical areas and climate change, through assessing SEV to fishing and tourism in the Spanish coastal system. We found that those areas with a high dependency on one single industry, i.e., tourism or fishing, are more likely to present higher SEV than other areas. For example, high dependency on tourism determined the high SEV of "Las Palmas" and "Santa Cruz de Tenerife". Both provinces are among the most popular tourist destinations in the European Union hosting more than 13,000,000 foreign tourists per year (Eurostat, 2019). We also found that the interlinkages between SEV dimensions are essential to understand the vulnerability of coastal systems. For example, the Balearic Islands are also highly dependent on tourism and have similar recovery potential of the fish community to "Las Palmas" and "Santa Cruz de Tenerife", yet its higher adaptive capacity of the social system lessens its SEV. By assessing SEV to fishing and tourism, we are also able to unravel which coastal regions are more threatened by both pressures. For example, Malaga does not show a high dependency on a unique industry (tourism or fishing), yet it presents a high SEV. This province hosts an important fishing heritage since Phoenician and Roman times, with archeological records along its coastline (Consejería de Agricultura y Pesca, 2007). However in the 60s, with the Spanish touristic "boom", Malaga also stood as a significant tourism destination (Mellado, 2013). Nowadays Malaga withstands moderate dependency on both tourism and fishing industries but the relatively low adaptive capacity of the Malaga social system and the low recovery potential of the fish community accounted for its high SEV.

Second, we have advanced the study of SEV in coastal systems by including different biodiversity metrics (species richness and functional diversity) in the assessment of the recovery capacity of the ecological system. Several researchers have included species richness in SEV assessments. For example, Cinner et al. (2013) and Siegel et al. (2019) included coral species richness and fish species richness in their studies to assess the recovery potential of the fish community. Cinner et al. (2013) also included the diversity of herbivores, representing one of the first studies including functional traits information when assessing SEV. Yet, recent studies have shown that different biodiversity metrics may respond differently to socio-economic factors (Lazzari et al., 2020). For example, whereas species richness is more associated with the type of territorial uses (i.e., natural land uses and protected surface), functional diversity is more associated with economic aspects (i.e., annual income per inhabitant and employment rate) (Lazzari et al., 2020). Therefore, we argue that integrating multiple biodiversity metrics is essential to assess SEV.

5.2. Management implications of SEV assessment

By assessing why some regions have low SEV, we can ascertain the management actions that lead to resilience. Since SEV and social-ecological resilience are opposing concepts that are strongly related (Folke et al., 2002; Miller et al., 2010), the identification of those dimensions that characterize low SEV provinces would point to key actions to increase the resilience of the coastal system. Our results suggest that management interventions oriented to reduce the dependency on tourism and fishing, increase the adaptive capacity of the social system, and reduce the pressure from both industries over the ecological system, may enhance the social-ecological resilience. In addition, our results suggest that those provinces with high pressure from local recreational activities show lower SEV. This result might prove that management plans that consider local recreational activities that foster a relationship to the proximal coastal system are essential for building social-ecological resilience (Davidson-Hunt and Berkes, 2003; Blázquez-Salom et al., 2019).

"La Coruña" and "Pontevedra" were the most social-ecological vulnerable provinces. The high dependency on fishing, the low recovery potential of the fish community, and the high pressure from fishing activities were the factors contributing to their high SEV. Spain has 11 marine protected areas oriented to manage fishing resources under national jurisdiction, but almost 75% are located in the Mediterranean Sea and none of them are in the northwestern Spanish Atlantic coast (Sanabria-Fernandez et al., 2019). "La Coruña" and "Pontevedra" count with less than 6% of their coastal system protected under regional policies. Therefore, increasing efforts to protect northwest Spain considering its social-ecological characteristics seems to be an alternative to increase the recovery potential of the fish community (Franke et al., 2020). Besides, "La Coruña" and "Pontevedra" present a long tradition of marine resource exploitation, being a significant fishing region for Spain and the European Union (Pita et al., 2018). For these regions, we suggest to promote livelihood diversification, since it may reduce the high dependency on fishing and, therefore, reduce their SEV. One way to diversify livelihoods is to promote tourist activities that are related to the culture and marine heritage. In fact, fishing-tourism represents the first action for the economic diversification of fisheries in Spain (BOE n° 313, 27AD; Piñeiro-Antelo and Lois-González, 2019). However, the implementation of such measures must be done with caution, as tourism is also an important pressure for marine biodiversity (Blancas et al., 2010).

The uncontrolled coastal urbanization associated with tourism and the increased population during the peak season are important pressures for marine biodiversity (Blancas et al., 2010). Our results showed that, even with high ecological recovery potential of the fish community, "Las Palmas" and "Santa Cruz de Tenerife" showed high SEV. The high dependency on tourism, the low adaptive capacity of their social system and the high pressure from recreational activities contributed to increasing their SEV. National and international policy agendas are struggling to encourage the restructuration of the tourism industry towards eco-friendlier activities that foster the economic development of local communities minimizing the impacts on marine ecosystems, e.g., Sustainable Development Goals 8, 12, and 14, or the European Commission in its Agenda for a sustainable and competitive European tourism (Blancas et al., 2010; Blázquez-Salom et al., 2019). Besides, management interventions oriented to reduce the SEV by increasing the adaptive capacity of the social system of tourism-dependent provinces should i) develop innovative tourism alternatives such as ecotourism, ii) encourage community participation in planning processes, iii) boost the local economy through job creation and use of local products, and iv) foster environmental education programs (Muganda et al., 2013).

5.3. Limitations of the study

We focused on fishing and tourism as the main impacted and impacting industries, yet other activities may also affect coastal systems and conditioning their SEV (Thiault et al., 2017; Thiault et al., 2019b). For example, the Mediterranean province of "Murcia" has the "Mar Menor", one of the largest coastal lagoons in the Mediterranean Sea. After decades of suffering the cumulative impact of anthropogenic activities, the Mar Menor collapsed in 2019 without recovery expectations (Crespo, 2019). Surprisingly, despite this province has recently suffered the social-ecological collapse of its coastal lagoon, our findings showed that "Murcia" had low SEV. The main reason for the collapse in the Mar Menor was the excess of nutrients and pollutants from intensive agriculture (Conesa and Jiménez-Cárceles, 2007), drivers of change that we did not address in this study. A broader application of this framework to explore the impacts of additional pressures such as agriculture may help to understand the SEV of coastal systems.

Furthermore, even though this study focused on the SEV assessment of coastal systems to fishing and tourism, we recognized the interconnection between the impact of these pressures at the local scale and the global drivers underpinning both pressures such as global trade and governance (Díaz et al., 2019). Telecoupling processes, i.e., socio-economic and environmental interactions between human-nature systems over long distances and across scales (from local to global, Liu et al., 2013; Martín-López et al., 2019), have reconfigured fishing and tourism industries. For example, Carlson et al. (2020) recently found that the study of social-ecological interactions along spatial and temporal scales may help to understand the underlying fishing fluxes, integrate the social-ecological complexities for better governance, and foster fisheries sustainability from local to global. Díaz et al. (2019) reported that the European Union, the United States, and Japan, together accounted for ~64% of the global fish imports, whereas those middle- and lower-income regions (according to World Bank income classification) accounted for 59% of the total volume of traded fish. These exchanges are mainly controlled by a handful of transnational corporations (Osterblom et al., 2015). This example shows that although the vulnerability to fishing is experienced at local and national scales, the drivers of change behind fishing trade operate on a global scale. Future research on SEV should consider the telecoupling processes by which global drivers cause local impacts on coastal systems.

Finally, although this study advances the understanding of the spatial variation of SEV, little is known about its temporal variation. Social-ecological associations that are vulnerable in one period are not necessarily vulnerable in another period (Adger, 2006). Socio-economic fluctuations associated with changes in the political economy of markets and even with health emergencies, such as the recent Covid-19, may modulate the social vulnerability of coastal systems (Adger and Kelly, 1999). But also, ecological fluctuations that respond to population dynamics and environmental oscillations, such as the North Atlantic Oscillation, may modify the ecological vulnerability (Drinkwater et al., 2003). Understanding how the interaction between both systems evolves may help developing management interventions that are flexible over time, leading to systems that are better able to cope with future perturbations.

6. Conclusions

Our findings contribute to the understanding of the social-ecological vulnerability (SEV) of temperate coastal systems. By applying the SEV framework to the Spanish coastal system, our research advanced the study of SEV of temperate coastal systems to fishing and tourism. We detected priority areas where management actions were needed and we identified the strengths and weaknesses that contribute to SEV. Our results reveal that high dependency on one single industry, i.e., tourism or fishing, are more likely to present higher SEV, suggesting that the livelihood diversification is a possible strategy to reduce vulnerability. Furthermore, based on the knowledge gaps of this study, we suggest that future SEV assessment of coastal systems should address land-based pressures such as agriculture, consider social-ecological interactions over distances, and advance the understanding of social-ecological temporal dynamics. This research defines the SEV framework as a promising tool, not only to spatially detect SEV hotspots, but also to identify the key social and ecological dimensions underpinning vulnerability, and whose management may lead to increase the resilience of coastal temperate systems.

CRediT authorship contribution statement

Natali Lazzari: Conceptualization, Formal analysis, Investigation, Writing – original draft, Visualization, Funding acquisition. **Mikel A. Becerro:** Writing – review & editing, Funding acquisition. **Jose A. Sanabria-Fernandez:** Investigation, Writing – review & editing, Funding acquisition. **Berta Martín-López:** Conceptualization, Writing – review & editing, Supervision.

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.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2021.147078.

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