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Long-term assessment of the effectiveness of coastal protection regulations in conserving natural habitats in Spain

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ABSTRACT

Spain has undergone rapid socioeconomic development in the past three decades. This has been linked to massive residential and infrastructural development based on a short-term, profitable and resource-intensive consuming model. As a result, large amounts of agricultural, natural and semi-natural soils have been lost to artificial areas, especially around main cities and on the coast. In this study, we assessed the effectiveness of the Spanish Shores Act at preventing land development in two biogeographical regions and three administrative scales between 1988 and 2020 using a BACI design and remote sensing data. We also analysed the combined effect of other regulations to prevent land development on the coast. The Shores Act was effective in reducing land development although moderate to substantial land development occurred in the zones affected by the Law, especially in the Mediterranean region. Adding other sectoral regulations to the Shores Act notably and consistently reduced land development across regions. Among them, cumulative protected area (PA) regulations were most effective in reducing coastal land development. The use of satellite images, especially Sentinel 2A MSI data within a BACI design, proved a useful method for assessing the effectiveness of fine-scale objectives of environmental policies such as the Shores Act.

1. Introduction

Coastal areas are becoming increasingly modified due to the concentration of human populations and activities leading to intense, broad-scale land use-land cover (LULC) changes (Hadley, 2009; Dias et al., 2013). Currently, over 44% of the world's population lives within 150 km from the sea, and that proportion keeps rising (United Nations, 2016). These trends put important pressures on natural ecosystems and related biodiversity. Coastal ecosystems are places with high biological diversity that provide a wide range of services to human populations (Burke et al., 2001; MEA, 2005). They are also spatially limited to a narrow fringe of land where unique ecological conditions resulting from terrestrial and marine influences converge. Such special ecological requirements make coastal biodiversity both rare and vulnerable, and thus relevant from a conservation perspective (Halliday, 2005). By 2005, coastal habitats had been the broad ecosystem type most historically impacted by a combination of human-induced drivers such as habitat alteration, climate change, invasive species, overexploitation of resources and pollution (MEA, 2005). They were also the global habitat types that are undergoing the greatest increasing impacts from such drivers in recent times (MEA, 2005). Coastal degradation trends have continued unabated resulting in broad ecosystem deterioration and decline of ecosystem services provided by coastal biodiversity worldwide (IPBES, 2019).

The Mediterranean region is recognised as one of the global biodiversity hotspots where high degrees of species richness and endemicity coexist with high rates of habitat loss (Myers et al., 2000; UNEP-MAP, 2016). More than 480 million people live in the region, of whom 55% concentrate in its coastal hydrological basins and over one third inhabit its 46,000 km of coastline (EEA, 2020). Moreover, the region hosts around one third of the world's tourist arrivals, most of them located in coastal areas (UNEP-MAP, 2016). The fragile and spatially limited Mediterranean coastal biodiversity is subject to multiple pressures, notably land development for housing, transport infrastructure and tourism facilities, which result in substantial natural habitat degradation and loss (EEA, 2020; Romano et al., 2017).

Spain is a Euro-Mediterranean country rich in biodiversity. The country harbours 54% of all known species in the European continent (Montes et al., 2011). Its south-eastern side is considered a regional plant biodiversity hotspot (Médail and Quézel, 1999) within the global

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Mediterranean hotspot (Myers et al., 2000). The 9300 km of the Spanish coasts are highly diverse in terms of lithology, relief and hydrological characteristics, with cliffs predominating in the northern, higher Atlantic coast and low, sandy beaches being more abundant along the Mediterranean coast. The diversity of height, slope and orientation of the Spanish coast has led to nine coastal provinces for ecological monitoring being proposed (Spanish Government, 2019). In spite of the high conservation importance of its coastal areas (Spanish Government, 2016), coastal habitat degradation in a well-known, long-lasting issue in Spain (Cendrero, 1989; Jiménez et al., 2005; Montes et al., 2011; Greenpeace, 2019). Massive artificial developments in the past three decades, chiefly along the Mediterranean coast of Spain, have resulted in sustainability issues such as coastal erosion, water scarcity, increased flood risk, local climate alteration, increased air and water pollution, or littering (García and Servera, 2004; Stellmes et al., 2013; Williams et al., 2016; Toubes et al., 2017). All those issues being serious, ecosystem degradation and destruction can however be considered the main environmental impact caused by coastal development due to the fragility, limited spatial distribution and irreplaceability of coastal ecosystems (Montes et al., 2011). Residential, tourism and infrastructure development have resulted in some Spanish provinces having more than 50% of their seafront areas built (Greenpeace, 2019) and in over 75% of the ecosystem services provided by coastal areas being degraded (Montes et al., 2011). Moreover, socioeconomic issues linked to coastal overcrowding, reduced visitor's satisfaction, touristification, rising prices, economic dependence or high vulnerability to economic crises are to be added to large-scale land development along the Spanish coasts (Perles-Ribes et al., 2016; Basterretxea-Iribar et al., 2019; Rodríguez-Pérez de Arenaza et al., 2019).

Massive land development leading to coastal degradation in Spain has resulted from a number of factors including: migration of inland populations towards coastal areas; strong dependence of urban development by town councils' budgets; deficient planning supervision; political corruption; absence of political accountability; and prevalence of beach tourism, with widespread acquisition of holiday homes by nationals and foreigners (Jiménez, 2009; Esteban and Altuzarra, 2016). Tourism is an essential economic sector in Spain. It accounts for 12.4% of the country's GDP and provides 12.9% of jobs (INE, 2020), Spain being the second world's tourism destination (UNWTO, 2019). The Spanish Government reacted to these environmentally worrisome trends by passing the Shores Act 22/1988 aimed at the conservation and sustainable use of coastal resources (Spanish Government, 1988). Some previous studies have assessed the effectiveness of environmental policy tools in preventing land development in Spanish coastal areas such as the Shores Act itself (Greenpeace, 2019) or protected areas (PAs; Rodríguez-Rodríguez et al., 2019b), with contrasting results. Other studies have assessed the Shores Act from a legal perspective, highlighting competence-sharing issues and some innovative conservation issues brought in by it (García, 2009). However, no study has yet specifically quantified the effect of the only regulation aimed at conserving coastal areas in Spain in the long term accounting for confounding factors such as climate, additional regulations or administrative competencies.

Evaluation should be an integral part of any policy cycle (Jacob et al., 2019). Remote sensing (RS) has greatly helped in accurately and consistently assessing progress of environmental pressures such as deforestation or urbanisation over large areas (Pedlowski et al., 1997; Hansen and Loveland, 2012; Olsen et al., 2013). As such, it has great potential to assist policy making and review (De Leeuw et al., 2010). Satellite data and other Geographic Information Systems (GIS) tools have been previously used for the assessment of coastal ecosystems and the effect of urbanisation in highly populated locations (Twumasi and Merem, 2006; Shalaby and Tateishi, 2007), and in sensitive ecosystems (Green et al., 1996; Hedley et al., 2016). Here, we compared RS data in the 1988–2020 period to answer a number of research questions: 1) Has the Shores Act been effective in conserving natural coastal habitats and landscapes in Spain in the long term by avoiding land development?; 2) What are the bio-geographic and administrative units (regions, provinces, municipalities) where it has been most and least effective?; 3) Have additional sectoral regulations increased the conservation effectiveness of the Act 22/1988?; and 4) Are satellite data suitable for assessing fine-scale environmental policy objectives such as restricting land development on spatially limited natural habitats?

2. Methods

2.1. The Shores Act: legal zones

The Shores Act's main objectives are: defining, conserving, sustainably using and patrolling coastal areas in the country; granting the public use of the coast; and conserving coastal landscapes, the coastal environment and cultural heritage (Spanish Government, 1988). The Shores Act defines two zones where land development is restricted to essential infrastructures that can only be located at the seafront on habitat and landscape conservation grounds: (1) the Public Coastal Domain (PCD), and (2) the PCD's Protection Zone (PZ). The PCD includes: the country's territorial waters and seabed up to the highest seawater mark level ever known; river mouth' beds as far inland as up to where tides are felt; beaches and dunes up to the necessary limit to warrant beach stability and coastal defense; the vertical part of seafront cliffs; areas gained to the sea or invaded by the sea; islets and natural islands in coastal waters and river mouths; and State-owned facilities on the coast, including ports (Spanish Government, 1988). The Protection Zone of the PCD is aimed at conserving the integrity and functionality of the PCD. Land development activities such as urbanisation, infrastructure development, mining, power line installations, rubble dumping or billboard setting are prohibited in the PCD and its Protection Zone since 1988 (Spanish Government, 1988). The PCD's Protection Zone includes a 100 m inland stripe from the PCD. Those zones could be expanded another 100 m inland by regional or local authorities, or reduced to a minimum of 20 m around tide-influenced river mouths (Spanish Government, 1988).

2.2. Study area

We used the official digital cartography of the terrestrial part of the PCD and its Protection Zone (Spanish Government, 2021a). We added a Control Zone (CZ) to those zones, which covered an additional 100 m fringe inland from the PCD or its Protection Zone in order to validly evaluate the effectiveness of the Act. Due to the narrow nature of our study area, whose width can in some cases be less than 50 m inland from the coastline, a 1 km buffer was generated over the PCD to ensure the availability of areas to train and evaluate the supervised classification model (Fig. 1). The Canary Islands were excluded from the analysis due to poor RS data quality that disqualified most of the region's study area and hampered valid comparison between the study's time points.

2.3. Research design

We used a Before-After-Control-Impact (BACI) research design whereby we assessed land-use transitions from natural or semi-natural coastal ecosystems to artificial uses or vice versa through the Proportional Absolute Change in Artificial Area (PACA) between 1988 (*Before*; when the Shores Act was enacted; *i.e.*, the sought impact) and 2020 (*After*) in the two zones protected by the law, as cases: PCD (63,286 ha) and PZ (45,955 ha) and in a continuous, adjacent *Control* Zone (CZ) spanning an additional 100 m inland from the PCD or its Protection Zone (75,637 ha). We used the Control Zone as a counterfactual, as suggested for policy evaluation (Bengston et al., 2004). The *Control Zone* is the most environmentally similar one to compare with both zones in the Shores Act and is similarly subject to high land development pressure (Greenpeace, 2018). We computed PACA between 1988 and 2020

Fig. 1. Zones in the study area with zoomed example locations.

through the following equation:

$$\text{PACA } (\%) = \sum \left(\frac{ARTx(t2) - ARTx(t1)}{AREAx} \right) \text{x } 100$$

Where $\mathrm{ART}x_{(t1)}$ is the sum of artificial areas in zone x in 1988 (in ha.), and $\mathrm{ART}x_{(t2)}$ is that sum in 2020. AREAx is the total area of zone x in ha. PACA values can range from −100% (total re-naturalisation from complete development of a zone in a given period) to +100% (complete development from null land development). We assessed the effectiveness of the Act at five geographic and administrative scales with official GIS data (IGN, 2021a): All Spain (NUT-1); biogeographical regions (EEA, 2019); Autonomous Regions (NUT-2); provinces (NUT-3); and municipalities (LAU-NUT-4; European Commission, 2020).

2.4. Additional regulations

We replicated the same analysis over the part of the Spanish coast where the Shores Act spatially overlapped with other sectoral regulations imposing additional restrictions to land development. We considered the following official digital layers: 1) the Public Water Domain and its Protection Zone, spanning generically 5 m on each side of riverbeds and water masses up to the highest watermark level (Spanish Government, 1986, 2021b), 2) Public Utility Forests (Spanish Government, 2003); and 3) PAs (Spanish Government, 2007) designated until December of 2017 (Spanish Government, 2021c). Both the Public Water Domain and Public Utility Forests had been established before the Act 22/1988, Public utility Forests being a historical legal category for forest management since the XIXth century (Ibort y Pardo, 2017). We included all PAs designated until December of 2017 in order to allow them a minimal time of three years to show some effectiveness against land development after designation (Rodríguez-Rodríguez and Martínez-Vega, 2018). We classified PAs according to their legal stringency as 'Reserves' (*i.e.*, IUCN's stringent management categories I & II, including Nature Reserves and National Parks; Dudley, 2008) or legally lenient 'Multiple-Use PAs' (the remainder of the IUCN's management categories; e.g. Nature Parks or Natura, 2000 sites), as they have shown different performance against land use changes in Spain (Rodríguez-Rodríguez and Martínez-Vega, 2017, 2019a). The four sectoral regulation layers were merged and PACA figures were similarly computed in the study area covered by additional regulations according to each combination of overlapping sectoral regulations.

2.5. Data description and analysis

For the assessment of the effectiveness of the Shores Act 22/1988, maps of developed areas were generated before (1988) and after (2020) the implementation of the Act. We used satellite data from Landsat-5 TM for 1988 and Sentinel-2 MSI data for 2020. A preliminary accuracy test was done between available data from Landsat 8 OLI and Sentinel 2 for 2020 to choose the best data source for mapping urban areas on the Spanish coast (Appendix A). Aerial photos obtained from the National Cartography Service from 1988 to 2020 were used to label the training and validation samples (IGN, 2021b).

Fig. 2 shows a workflow of the methodology applied. Firstly, all images available for the years 1988 and 2020 were retrieved from the Google Earth Engine Data Catalog, specifically from the Landsat collection (product reference: LANDSAT/LT05/C01/T1_SR) and the Sentinel collection (product reference: COPERNICUS/S2_SR) (Gorelick et al., 2017). Both collections offer a Surface Reflectance product in which atmospheric, radiometric and geometric corrections have been made. Therefore, no preprocessing was required. A polygon was manually digitised covering only the coastal area of the Spanish Peninsula and the Balearic archipelago. We excluded images with cloud cover over 20%. A total of 523 images for 1988 and 2837 images for 2020 were used to create a single image composite per year, using a median composite of each of the bands, except the thermal bands for Landsat. The Landsat 5TM path/row and Sentinel-2 tiles used are listed in Appendix B.

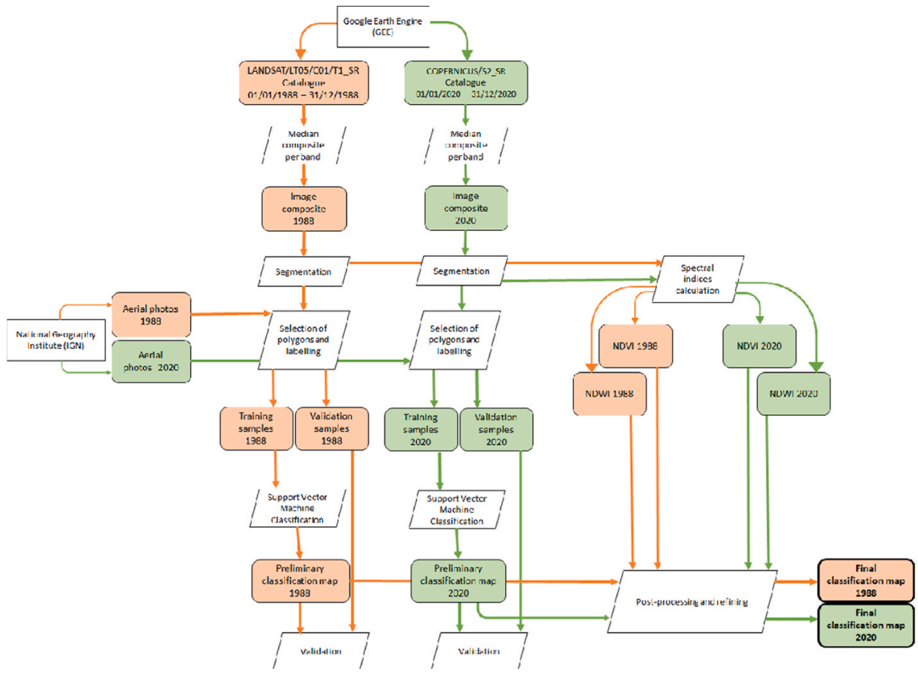

Fig. 2. Methodological workflow to obtain a classification map from satellite data.

The aim behind the composition using the median was to obtain a solid value for developed areas, as their reflectance does not vary along the year. To make both datasets comparable, the spatial resolution of Sentinel-2 was reduced from 10 m to 30 m to match the pixel size of Landsat 5TM. In addition, not all bands from Sentinel-2 were used, but only those that have a counterpart in Landsat 5TM (Appendix C). Then, these two composites were used in a supervised classification to generate a map of developed areas.

We performed a test on a sample of the territory with Random Forest (RF) and Support Vector Machine (SVM) classifiers and calculated confusion matrices to assess the classification accuracy. Overall accuracy, user's accuracy, producer's accuracy and Kappa's coefficient were used (Congalton, 1991). The users' accuracy indicates the probability of a classified pixel to correctly represent a category on the ground. The producer's accuracy indicates the probability of a pixel being correctly identified, while Kappa's coefficient assesses how well the classification performed as compared to random values (Liu et al., 2007). Test results concluded that SVM was more suitable for our purpose as it had both a higher global accuracy (86.23% for SVM vs 78.39% for RF) and a higher accuracy for every land cover in both user and producer's accuracy (Appendix D). Therefore, we used Support Vector Machine (Mountrakis et al., 2011; Pal, 2005a) for the generation of the maps. These results coincide with the observation from previous authors, which point out that RF are good classifiers for large datasets, easy to implement and resilient to noise and over-dimensioning (Pal, 2005b; Meinan et al., 2020). However, they are very dependent on the design and selection of training samples (Belgiu and Drăguţ, 2016). On the other hand, SVM can achieve a high accuracy even with small sampling sizes (Pal, 2005a; Tamiminia et al., 2020).

For the classification, we clipped the image composite to the study area, meaning the PCD, the PZ and the CZ. Besides, we generated two sample datasets, one for training the model and a second one for validating the model. For the generation of samples, segmentation was done using ArcGIS Pro v.2.8. using all bands of the image composite. The samples were selected and tagged manually from the segmented polygons, covering classes of developed and non-developed polygons, by photointerpretation of the aerial photos (Millard and Richardson, 2015; Appendices E to G). The pixels overlapping the polygons of each class were used as training samples. The number of polygons, their area in hectares, the total number of pixels that were used for each of the classes, as well as details of the assessment points used, are presented in Appendix H. The classes used to feed the classification are listed in Table 1. The 'non-developed' class encompassed vegetated areas (pastures, grasslands, shrublands, forests), bare soil and rocks, beaches, wetlands and water. Afterwards, we merged all classes under 'developed' or 'non-developed', obtaining a simplified map of two classes.

2.6. Post-processing

A preliminary test showed that the total accuracy of the map generated with SVM classification, with Sentinel-2 image for 2020, was around 86%. However, a visual inspection revealed some classes that were difficult to classify. Among others, it was difficult to separate gardens and parks within developed areas from natural vegetation. Beaches and cliffs were sometimes confused with developed sites. Moreover, tidal zones were sometimes classified as water and some other times, as developed areas. For this reason, and based on previous studies (Chunyang et al., 2010; Goldblatt et al., 2016, 2018; Kaplan and Avdan, 2017), we used spectral indices to refine our results. The Normalized Difference Vegetation Index (NDVI; Rouse et al., 1974) and the Normalized Difference Water Index (NDWI; Gao, 1996) were used to clean up errors of commission out of the SVM maps. These indices were calculated on the image composite bands for years 1988 and 2020. According to Goldblatt et al. (2016, 2018), the NDWI values between 0 and 1 separates water masses from other classes. In our experience, we found the range 0.1–1 to be more effective. In addition, those authors suggested that NDVI values between 0.35 and 1 classify vegetated areas under 'non-developed' class. In our case, we selected the range 0.55–1.

The resulting maps showing land developed areas in 1988 and 2020

Table 1
Classes defined for classification using Support Vector Machine.

Non-developed	Developed
Vegetated	Developed
Arid	Developed with vegetation
Bare rock or soil	
Beach	
Wetland	
Water	

were intersected at five geographic and administrative scales (all Spain, biogeographical regions, autonomous regions, provinces and municipalities) using ArcGIS Pro v. 2.8 and PACA values were produced. After verifying the non-normal distributions of variables, Spearman correlation tests and Kruskal-Wallis tests were performed to ascertain statistical associations and differences between PACA and a number of independent variables for a *p-value* = 0.05.

3. Results

3.1. Map accuracy

The accuracy of the final maps generated using SVM and post-processing using SVIs is shown in Appendix I. The confusion matrices show that maps from both dates had a total accuracy above 85%, being the map based on Sentinel 2 slightly more accurate (>90%; Appendix I). The producer's and user's accuracies per class were on average similar, around 88%. A visual inspection of errors revealed that the errors of commission for the 'developed' class were associated with bare surfaces, such as cliffs and sand beaches, and plastic greenhouses. The errors of omission were generally related to urban green areas, which are commonly confused with natural vegetation ('non developed areas' class).

3.2. Effectiveness of the Shores Act

Land development was lower in the zones covered by the Act than in the Control Zone between 1988 and 2020. Specifically, the Protection Zone experienced substantially less land development than the Control Zone consistently in all the study area ($PACA_{(PZ\text{-}CZ)} = -12.71\%$), whereas the PCD experienced moderately less land development than the Control Zone ($PACA_{(PCD\text{-}CZ)} = -4.84\%$) although more geographically varied, ranging from lesser to greater land development than the Control zone depending on the Autonomous Region (Table 2).

3.3. Bioregional and administrative effectiveness

The Shores Act was most effective in the Mediterranean region. PACA was 12.53% and 13.13% smaller in the PCD and the Protection Zone compared with Mediterranean Control Zones, respectively. By Autonomous regions, PACA difference with Control Zones was the greatest in the Balearic Islands at −21.19% and −19.21% for the PCD and Protection Zone, respectively. The Autonomous regions where the Shores Act was least effective were Murcia and Asturias, both with worse land development figures in their PCDs than in their Control Zones. By province, Cadiz and Alicante had the greatest PACA differences with their Control Zones, whereas Granada experienced substantially more PACA in its PCD and Protection Zone than in its Control Zone (Table 2). The provinces of Granada, Almeria and Barcelona, all in the Mediterranean region, had the greatest proportions of all their zones (> 65% on average) developed in 2020. By municipality, the ten municipalities with their Protection Zones comprising more than 5 ha that had the greatest PACA values were in the Mediterranean region: 40% of them were in Andalusia (75% of these in the province of Granada); 30% were in Catalonia (all in the Barcelona province) and 30%, in Valencia Region (Table 3).

Fig. 3 summarises PACA results at the three administrative scales used.

3.4. Effect of additional regulations

Adding other sectoral regulations that restrict land development to the Shores Act substantially and consistently reduced land development across Spanish coastal areas between 1988 and 2020 (Table 4). PACA reduction due to legal overlaps was the greatest in the Mediterranean region, especially in Catalonia and Andalusia.

Table 2
Area (in hectares), Proportional Absolute Change in Artificial Areas (PACA; in percentage), and proportion of developed areas (in percentage) in 2020 in the three zones of the study area, by Biogeographical region, Autonomous Region, province, and in the whole country.

Scale	Area of the study Zones (ha)			PACA (%)			Total built (%) in 2020		
	PCD	PZ	CZ	PCD	PZ	CZ	PCD	PZ	CZ
ATLANTIC REGION	**20,876**	**24,356**	**36,163**	**18.77**	**5.80**	**16.32**	**24.59**	**6.20**	**19.30**
Cantabria[a]	5050	4307	5675	9.52	3.84	13.51	13.27	4.06	15.73
Galicia	8804	12,181	17,892	20.40	7.15	17.43	26.70	7.55	20.38
La Coruña	4467	6679	9485	17.92	5.42	14.88	24.27	5.77	17.65
Lugo	1114	1554	2359	11.74	3.00	8.09	14.01	3.05	8.29
Pontevedra	3224	3948	6049	26.84	11.71	25.06	34.46	12.33	29.38
Basque Country	4700	2879	5664	25.02	9.47	24.99	30.16	10.63	30.89
Vizcaya	3149	1400	2975	28.05	7.44	25.35	33.50	8.73	30.96
Guipuzcoa	1551	1478	2689	18.85	11.38	24.59	23.39	12.43	30.80
Principality of Asturias[a]	2322	4990	6932	20.08	2.09	8.68	29.96	2.20	10.00
MEDITERRANEAN REGION	**42,410**	**21,598**	**39,473**	**22.31**	**21.72**	**34.85**	**32.42**	**27.59**	**50.08**
Andalusia	26,792	12,497	17,666	17.30	19.31	30.16	23.25	22.76	40.87
Almeria	1280	1301	1910	56.91	46.91	52.79	73.49	56.00	69.22
Cadiz	10,852	3395	4871	11.44	14.03	28.18	15.72	16.54	39.86
Granada	422	633	1082	68.37	53.28	47.00	81.11	58.31	60.45
Huelva	8505	3512	4041	7.01	6.34	15.00	8.67	7.63	21.20
Malaga	1470	936	2542	56.70	45.16	47.74	69.13	51.27	63.94
Seville	4262	2719	3221	22.17	12.63	19.20	34.90	16.07	25.48
Catalonia	4819	2262	6137	38.42	34.31	43.88	61.18	47.14	65.24
Barcelona	2598	778	2064	38.47	37.42	43.82	63.63	58.53	72.98
Gerona	932	952	2697	33.87	30.38	43.01	48.11	36.72	57.77
Tarragona	1289	531	1377	41.61	36.81	45.69	65.68	49.14	68.28
Valencian Region	4708	2492	6494	36.66	26.37	38.48	60.28	38.07	61.41
Alicante	1276	1330	3370	25.65	27.57	41.57	48.57	38.82	61.41
Castellon	1312	650	1640	29.37	21.25	36.15	52.58	30.97	57.19
Valencia	2120	513	1485	47.80	29.75	34.04	72.08	45.13	66.08
Balearic Islands[a]	4715	3358	6928	14.42	16.40	35.60	18.25	18.96	43.77
Region of Murcia[a]	1022	901	1886	39.26	29.21	33.74	60.70	46.04	66.58
TOTAL SPAIN	**63,286**	**45,955**	**75,637**	**21.15**	**13.28**	**25.99**	**29.84**	**16.25**	**35.37**

Note: PCD: Public Coastal Domain; PZ: Protection Zone; CZ: Control Zone.
[a] Autonomous regions with just one province.

Table 3
Municipalities with their Protection Zones greater than 5 ha that developed most their Protection Zones in the period 1988–2020, ordered by their decreasing PACA values.

Municipality	Autonomous Region	Province	Protection Zone area (ha)	PACA (%)	Developed area in 2020 (%)
Albalat dels Sorells	Valencia	Valencia	5.25	85.73	86.23
Rubite	Andalusia	Granada	45.54	80.03	83.71
Meliana	Valencia	Valencia	23.32	79.86	84.02
Gavá	Catalonia	Barcelona	31.43	77.83	80.88
Cabrera de Mar	Catalonia	Barcelona	31.88	75.76	96.75
Albuñol	Andalusia	Granada	146.10	70.68	78.63
Sorvilán	Andalusia	Granada	39.67	68.81	69.26
Pilar de la Horadada	Valencia	Alicante	41.66	66.90	74.57
Sant Andreu de Llavaneres	Catalonia	Barcelona	14.36	66.57	81.77
Casares	Andalusia	Malaga	8.93	64.69	70.83

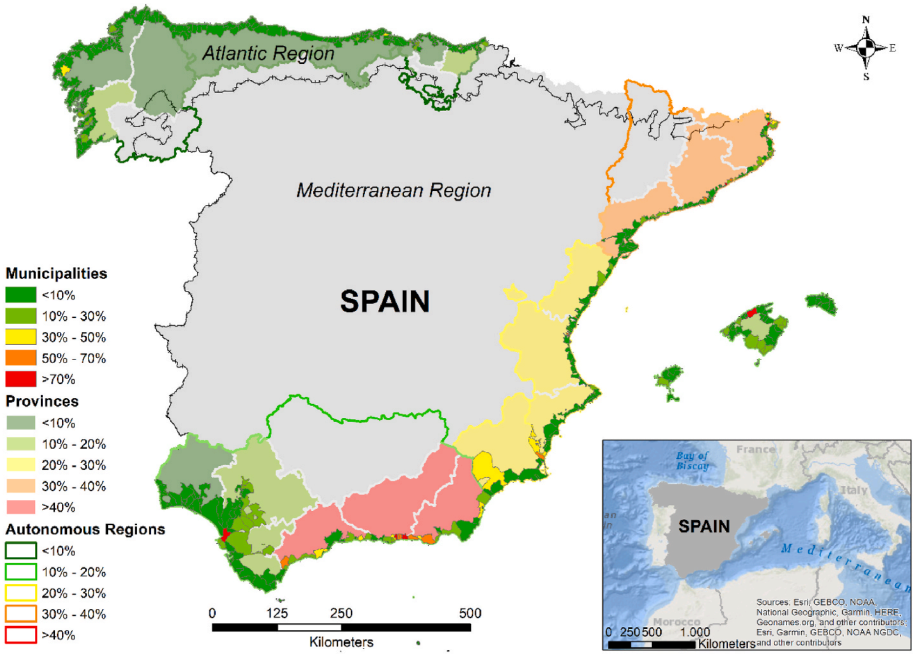

Fig. 3. Proportional Absolute Change in Artificial Areas (%) in the Protection Zone in areas covered only by the Shores Act by administrative units in Spain between 1988 and 2020.

Table 4
Proportional Absolute Change in Artificial Area of the three study zones (in percentage) in areas covered only by the Shores Act and in areas also covered by additional sectoral regulations (AR), by biogeographical and Autonomous Region.

Region	Proportional Absolute Change in Artificial Area (%)					
	PCD		PZ		CZ	
	Shores Act	AR	Shores Act	AR	Shores Act	AR
ATLANTIC REGION	18.77	3.38	5.80	2.11	16.32	5.22
Asturias	20.08	2.30	2.09	1.23	8.68	3.57
Basque Country	25.02	3.40	9.47	2.41	24.99	6.62
Cantabria	9.52	1.56	3.84	1.70	13.51	5.88
Galicia	20.40	4.43	7.15	2.40	17.43	5.46
MEDITERRANEAN REGION	22.31	1.94	21.72	5.64	34.85	7.89
Andalusia	17.30	1.12	19.31	4.34	30.16	4.95
Balearic Islands	14.42	5.37	16.40	6.34	35.60	10.02
Catalonia	38.42	1.64	34.31	6.16	43.88	9.99
Murcia	39.26	6.70	29.21	6.56	33.74	5.73
Valencia	36.66	5.22	26.37	6.74	38.48	8.69
TOTAL SPAIN	**21.15**	**2.27**	**13.28**	**4.31**	**25.99**	**7.15**

Note: PCD: Public Coastal Domain; PZ: Protection Zone; CZ: Control Zone; AR: Additional regulations.

There were no statistically significant differences in PACA between biogeographical regions or Zones. In contrast, there were statistically significant differences in PACA among Autonomous Regions ($\chi^2_{(8)} = 17.63$; $p = 0.024$), the lowest mean ranked PACA values corresponding to Cantabria and the greatest, to Murcia. There were also significant differences in PACA according to the combinations of additional protection regulations ($\chi^2_{(28)} = 55.64$; $p = 0.001$). The protection combinations greater than 40 ha that experienced the least PACA in all their zones were five multiple-use PA designations plus one reserve designation (mean PACA rank = 4.33) and five multiple-use PA designations plus one reserve designation plus Public Water Domain designation (mean PACA rank = 5.00). The combinations that experienced the greatest PACA in all their zones were the Public Water Domain on its own (mean PACA rank = 111.83), Public Utility Forest plus two multiple-use PA designations plus one reserve designation (mean PACA rank = 106.33), and a single multiple-use PA designation (mean PACA rank = 101.33; Appendix J).

There were statistically significant differences in PACA among multiple-use PA regulation combinations ($\chi^2_{(4)} = 34.31$; $p < 0.000$). Pairwise Bonferroni adjusted post-hoc tests for multiple-use PA regulation additions revealed statistically significant differences in PACA among five multiple-use PA regulations and one ($p < 0.000$), two ($p = 0.005$) and three multiple-use PA regulation overlaps ($p = 0.001$), and was close to significance for four multiple-use regulations ($p = 0.063$). Differences in PACA between one and two multiple-use regulation overlap were on the verge of statistical significance ($p = 0.051$). There was a strong statistically significantly negative correlation between the number of overlapping multiple-use PA designations and PACA ($rs_{(28)} = -0.694$; $p < 0.000$).

There were no statistically significant differences in PACA values among the four single additional regulations: ‘reserves’, ‘multiple-use PAs’, ‘Public Utility Forests’ and ‘Public Water Domain’ ($\chi^2_{(3)} = 5.73$; $p = 0.126$). However, when the four additional regulations were assessed in isolation for the three study zones, ‘reserves’ were totally effective at preventing land development in Atlantic Spain and the least effective regulation in the Mediterranean region, although the little area that ‘reserves’ cover in both regions make those results uncertain. The following most effective regulations were ‘Public Utility Forest’ in Atlantic Spain and ‘multiple-use PAs’ in Mediterranean Spain, respectively. ‘Public Water Domain’s values were the least effective regulation against land development in all Spain and in the Atlantic coastal areas, although they performed relatively better than most single sectoral categories in the Mediterranean coastal areas (Table 5).

4. Discussion

4.1. *Effectiveness of the Shores Act*

The Shores Act was moderately effective at preventing coastal land development in Spain between 1988 and 2020. Land development values generally followed an expected gradient among the three zones, according to their decreasing degree of protection from the Shores Act: CZ > PCD > PZ. This overall effectiveness aligns with previous studies in southern Spain (Malvárez et al., 2003) and is more positive than recent studies using GIS data from aerial photography and broader study areas that concluded that the Act was generally ineffective to prevent land development along the Spanish coasts (Greenpeace, 2019). Similar chiefly positive conservation outcomes of coastal regulations were also found from less comprehensive international assessments in the USA (Hershman et al., 1999), whereas poorer conservation outcomes were identified in India (Panigrahi and Mohanty, 2012), Nigeria (Twumasi and Merem, 2006), Egypt (Shalaby and Tateishi, 2007) and Greece (Kotsoni et al., 2017).

Avoided development occurred mostly in the Protection Zone, whereas notable land development happened in the PCD, sometimes even in greater proportion than in the Control Zone. Some important considerations must be made here. Firstly, both protected zones (PCD and PZ) performed generally better than Control Zones despite the fact that they were closer to the seafront and thus experienced greater development pressure (Conroy and Milosch, 2011; Greenpeace, 2018). Similar price-distance decay functions for houses and accommodation have been found for other natural amenities such as National Parks (Mandic and Petric, 2021). Secondly, both protected zones experienced some degree of land development, with few exceptions at municipal scale. Therefore, even though land development was generally reduced by the Act 22/1988, it was not prevented, resulting in moderate to very substantial increases in artificial coastal development, depending on the scale and unit of analysis. In that sense, the Law’s objective to conserve coastal landscapes and environment (Spanish Government, 1988) has just been partially met. Thirdly, the Shores Act permits the development of certain infrastructures that cannot be located elsewhere in the PCD, such as ports or lighthouses, even in the Protection Zone (Spanish Government, 1988). Thus, some of the PACA in the PCD and, to a lesser extent, in the Protection Zone, most likely does not result from regulation breaches or ineffectiveness but to exceptions in the Law. This is coherent with the generally better PACA values of the Protection Zone with regard to the PCD, where most of those exceptional infrastructures are located. Fourthly, our model could not discriminate properly between developed areas and plastic-covered areas, especially greenhouses, which cover large extensions close to the sea in some parts of the southeast of the country (Castro et al., 2019; Salvo-Tierra et al., 2020). Even though greenhouses are not usually located at the seafront, this methodological issue is likely to have caused some overestimation of soil sealing in areas of the provinces of Granada, Almeria and Murcia. Finally, other globally and Mediterranean-wide relevant variables that are likely to have influenced coastal land development and thus conditioned the Shores Act’s effectiveness at different spatial scales such as urban planning, housing prices, multi-scale policy coordination and implementation, mismanagement, corruption, etc., were not accounted for and can be just mentioned here (Bengston et al., 2004; Fiorini et al., 2019).

4.2. *Regional and local effectiveness*

Two clear coastal development patterns arose from our results: one with high developmental pressure along most of the Spanish Mediterranean coast, and a more sustainable coastal development in the Atlantic coast of the country. Such development patterns have been consistently found in a number of studies, and largely attributed to differences in climate between the sunny, hot and dry southern Mediterranean region and the cloudy, warm and wet northern Atlantic region of the country (Jiménez et al., 2005; Martínez-Fernández et al., 2015; Greenpeace, 2018; Rodríguez-Rodríguez et al., 2019b). That land development pattern replicates at all administrative scales, clearly indicating the need for the effective protection of the remaining natural and semi-natural habitats on the Spanish Mediterranean coast (Rodríguez-Rodríguez et al., 2019b; Salvo-Tierra et al., 2020). Contrasting Mediterranean-Atlantic coastal development patterns also replicate at finer scale in the southern region of Andalusia, the most populated region of Spain and the country’s top tourist destination (INE, 2021). Even though entirely belonging to the Mediterranean biogeographical region, coastal land development shows a clear divide between the highly artificial Mediterranean eastern provinces of Almeria, Granada and Malaga, and the lowly built rainier western provinces of Cadiz, Seville and Huelva. Salvo-Tierra et al. (2020) similarly found critical challenges for coastal plant connectivity in most of the Andalusian Mediterranean coastal PAs due to over-development with regard to the more

Table 5
Area (in hectares) and Proportional Absolute Change in Artificial Area (PACA, in percentage) values from single additional regulations by biogeographical region and study zone.

	Spain				Atlantic Region				Mediterranean Region			
	All Zones		Control Zone		All zones		Control Zone		All Zones		Control Zone	
Protection regulation	**Area (ha)**	**PACA (%)**	**Area (ha)**	**PACA (%)**	**Area (ha)**	**PACA (%)**	**Area (ha)**	**PACA (%)**	**Area (ha)**	**PACA (%)**	**Area (ha)**	**PACA (%)**
Reserve	103	3.13	31	0.00	91	0.00	31	0.00	12	27.19		
Multiple use PA	33,476	9.76	12895	14.76	9188	7.46	3368	11.14	24,288	10.64	9527	16.04
Public Utility Forest	2016	8.74	937	9.56	926	1.00	492	1.42	1,09	15.32	445	18.55
Public Water Domain	1725	11.31	267	19.25	776	9.81	188	16.71	949	12.53	79	25.30

Note: ‘All zones’ include the Public Coastal Domain, its Protection Zone and the Control Zone; PA: Protected area.

ecologically connected Atlantic coast of the region.

Infrastructures in the PCD allowed by Act 22/1988 such as ports or lighthouses may have contributed to poor PACA values in municipalities with limited coastal length, like many little municipalities along the Catalan coast. Such development exceptions in the Shores Act might help to partially explain the surprising fact that, unlike the Mediterranean region and despite its generally better land development values, PACA values in most of the Atlantic Regions' and provinces' PCD were greater than those in their Control zones. It is also noteworthy that some of the worst performing municipalities according to the proportion of their Protection Zones developed in 2020 such as Benidorm (Valencian region) or Castelldefels (Catalonia region) had a substantial proportion of their Protection Zones already developed before 1988. In contrast, municipalities such as Arenys de Mar, Sant Andreu de Llavaneres or Cabrera de Mar, all in the Catalonia region, developed over 77% of their Protection zones between 1988 and 2020. A recent study identified Catalonia as the Spanish region having experienced the greatest relative increase in coastal artificial areas between 1987 and 2014 (Greenpeace, 2018).

Massive residential and tourist developments have occurred in attractive locations along the Mediterranean coast, both legal and illegal (Greenpeace, 2018). Large dependence of local councils' budgets from development taxes, poor local and regional planning supervision, lenient accountability, scarce public participation in local planning, and political and administrative corruption have resulted in the infringement of the environmental and planning regulations and in their reduced effectiveness across the country (Jiménez, 2009; Esteban and Altuzarra, 2016; Fernández and Collado, 2017). Similar issues were found in other Mediterranean and Latin American settings (Dias et al., 2013; Kotsoni et al., 2017; Fiorini et al., 2019) and, to a lesser extent, also in the USA (Bengston et al., 2004). The extremely serious consequences of malfunctioning institutions for sustainable development should be highlighted (Rose-Ackerman, 2005). The decisions made in just one term may jeopardise long-lasting environmental policies, especially those related to conserving natural ecosystems from largely destructive and irreversible land development (Rodríguez-Rodríguez and Martínez-Vega, 2018). According to Act 22/1988, the competencies on delimitation, management, granting occupation and development of the PCD and its Protection Zone, and their surveillance belong to the Spanish central government (Spanish Government, 1988), which also holds legally binding local planning supervision responsibility on the activities carried out in those zones. Regional governments have environmental, territorial planning and local urban planning supervision competencies, whereas local councils can inform the delimitation and use of such zones, and develop their own urban plans. Thus, though the effectiveness of the Shores Act is the result of shared governance, the Spanish central governments between 1988 and 2020 have retained most competencies on land development in that area and should thus be held most accountable for its effectiveness across the country. Actually, alongside some restoration activities, the development of some remaining unsealed coastal areas to locate or extend artificial infrastructures such as sidewalks is still carried out by the Spanish Ministry of Environment itself (Spanish Government, 2021d). Other relevant activities on the coast carried out by the Spanish Government include the long-lasting accurate delimitation of the coastal zones (Spanish Government, 2022a) and, more recently, the passing of the Strategy for Coastal Adaptation to Climate Change (Spanish Government, 2016), or the drafting of regional Strategies for the Protection of the Coast from Erosion (Spanish Government, 2022b).

4.3. *Effect of additional regulations*

Other territorial regulations clearly reinforced the effectiveness of Act 22/1988 in reducing land development, similar to what previous studies found in Spain (Greenpeace, 2018; Rodríguez-Rodríguez and Martínez-Vega, 2018) and elsewhere (Bengston et al., 2004). Such effect was greater in the most pressured Mediterranean region, where it is most needed (Martínez-Fernández et al., 2015; Rodríguez-Rodríguez et al., 2019b). High development intensity was reported in other Mediterranean countries like Italy, where land development in its Southern Mediterranean PAs largely exceeds countrywide PA figures (Fiorini et al., 2019).

The most effective combination of regulations included five multiple-use PA regulations and one 'reserve' regulation, a very high and unusual combination of protection which was only attained in Doñana Nature Site in Western Andalusia. In this exceptional area, land development was even reversed due to ecological succession, restoration activities and/or image classification errors. As expected, association between different multiple-use PA regulations and reduced land development was found, with two overlapping designations seemingly providing sub-optimal yet good conservation outcomes. In their comprehensive study on the effectiveness of PAs in Spain, Rodríguez-Rodríguez and Martínez-Vega (2018) found that legally overlapping 'reserves' had been totally effective in preventing land development, whereas increasingly overlapping multiple-use PA categories in general did not consistently reduce land development. Those authors also found null land development in the highly protected and effectively managed Spanish Network of National Parks between 2005 and 2011 (Rodríguez-Rodríguez and Martínez-Vega, 2017). Nevertheless, the degree of legal restrictions and managerial resources that National Parks require make them a very environmentally effective though spatially restricted and socioeconomically challenging tool. The results from all these studies suggest that applying carefully selected combinations of protection regulations to specific sites might be the most efficient and politically feasible option and that such options should thus be explored to ensure the sustainability of future coastal planning in Spain.

Differences in the effectiveness of single additional protection regulations were apparent bio-geographically, with 'multiple-use PAs' being most effective (though with moderate effectiveness values) in the Mediterranean region, and 'reserves' and 'Public Utility Forests' providing the best outcomes in Atlantic Spain, respectively. Our results point to the fact that legally stringent 'reserves' were most effective in reducing land development on the coast, although the limited area that single reserves cover makes them more prone to methodological error. Moreover, lack of statistical significance among single additional protection regulations suggest caution when interpreting such results. Public Water Domain areas were the least effective single additional regulation. Such areas were suggested to provide some additional protection to PAs and their surroundings against land development in Spain (Rodríguez-Rodríguez and Martínez-Vega, 2018). Similarly, here we found them to provide some additional protection in the Mediterranean coastal areas of the country.

The fact that land development was only exceptionally completely stopped or reversed by additional regulations is worrisome for long-term coastal biodiversity conservation in the country (Greenpeace, 2018). The recent pace of destruction of coastal habitats and the foreseeable effects of climate change on coastal areas (Greenpeace, 2018; Losada et al., 2019) make it advisable to take bold steps to stop and reverse current trends. This should on the one hand imply implementing a moratorium to new coastal developments until an integral protection proposal of the remaining natural and semi-natural coastal habitats for the whole country is made. Such proposal should consider a meaningful ecological extent of coastal habitats, instead of their rather limited legal spatial extent according to the Shores Act (Greenpeace, 2019). On the other hand, effective coastal conservation would most certainly require relocating existing infrastructures further inland and restoring degraded coastal habitats of value for biodiversity conservation, ecosystem service provision or ecological connectivity, as the Spanish Strategy for Coastal Adaptation to Climate Change foresees (Spanish Government, 2016).

4.4. Use of remote sensing for coastal policy assessment

Satellite data arose as a suitable tool for the assessment of the LULC change-related objectives of the Spanish Shores Act 22/1988, given the large study area, its restricted spatial extent and the temporal component of the comparison. From the RS and spatial analysis point of view, any other dataset at finer scale, such as aerial photography, was discontinuous in time, thus not allowing a comprehensive and coherent evaluation of land development on the Spanish coast. Aerial photo campaigns take several years to cover the whole territory; therefore, there is not a time-shot for a particular year. Moreover, the dataset for 1988 was not complete for the entire coast, but only a few Autonomous Regions were covered (IGN, 2021b). A pixel size of 30 m proved sufficient for the identification and quantification of land developed areas in this study.

A study that intends to do a temporal analysis of more than 30 years using satellite data is only possible if Landsat data are used. On the other hand, we selected Sentinel 2 to cover the year 2020 because it is a more robust dataset than Landsat for several reasons. Firstly, the pixel size is finer (10 m versus 30 m from Landsat). Secondly, the sensor configuration provides more bands than Landsat (3 in the red edge region and one extra in the SWIR). Finally, because the revisit time is shorter (3–5 days versus 16 days for Landsat), increasing the probability of obtaining cloud-free images (Drusch et al., 2012; USGSUnited States Geological Survey, 2012). For this reason, the mean composite extracted from Google Earth Engine used around 500 Landsat images and more than 2000 Sentinel images. Our preliminary accuracy assessment between Landsat 8 OLI and Sentinel 2 determined that Sentinel 2 performed best in the classification of land development on Spanish coasts, while still being comparable to Landsat 5TM for 1988.

Here we just assessed some of the main objectives of the Shores Act, those with the greatest nature conservation component, using RS and GIS methods of great use in terms of data availability, cost-effectiveness and, to some extent, consistency. However, comprehensively assessing a multi-objective and complex territorial regulation linked to a wide range of stakeholders and a number of additional regulations such as the Shores Act would require complementary methods, such as official construction reporting (e.g. for refining nature and landscape conservation results from RS and GIS based on allowed exceptions to the Act), on the ground signaling (e.g. for defining and identifying the PCD) and surveillance (e.g. for assessing public access to the sea), or regular on site testing (e.g. for analysing water quality).

4.5. Methodological remarks

The fact that the Shores Act allows some infrastructures that cannot be located elsewhere in the PCD and even in its Control Zone has likely worsened the effectiveness of the Act to some extent, especially at local scale. Further studies could try to refine those findings considering permitted infrastructures like ports in the spatial analyses.

Despite the high accuracy observed in our results, over 86% total accuracy, there remain some limitations for an accurate classification of land developed areas on the Spanish coast using Landsat 5TM and Sentinel 2. One reason for the moderate success in classification may have been caused by the several adjustments that were made to make Landsat 5TM and Sentinel 2 comparable. Sentinel 2 was degraded to 30 m pixel and the bands that are not present in Landsat were not used. We observed errors of commission for the 'developed' class, which was sometimes taken for bare soils and plastic, while the errors of omission were in urban green areas. However, we expect that Sentinel 2, if used at 10 m resolution and in all its spectral bands, can overcome some of the accuracy limitations observed in the present study. The Sentinel 2 red edge and SWIR bands open a chance for properly discriminating the land cover classes that generated confusion in the model (i.e. cliffs, beaches, green-houses and urban green areas) not only during the classification analysis, but also using alternative spectral indices, specific for Sentinel 2 (and not Landsat), such as the Anthocyanin Reflectance Index (Gitelson et al., 2001), the Red Edge Inflexion Point (Vogelmann et al., 1993) or the Modified Soil Adjusted Ratio (Qi et al., 1994). Especially, urban green areas could eventually be discriminated by the red-edge and other water indices, as these areas are irrigated and low in non-photosynthetical material. Therefore, they have a high difference between the red and NIR areas (Alexander, 2020).

5. Conclusions

The Shores Act reduced land development on the heavily pressured Spanish coastal ecosystems, especially along the country's Mediterranean coast. The best and worst performance of the Act occurred in the Balearic Region on the one hand, and in Murcia and Asturias Regions on the other. Other territorial regulations, chiefly PA-related, substantially enhanced the Act's effectiveness against coastal development.

The effectiveness of the Act was influenced by climatic and governance factors, with local governments commonly overdeveloping their coastlines, regional governments inadequately restricting irregular urban developments, and the Spanish central government insufficiently assuming its responsibility to enforce Act 22/1988.

The RS data and methods we used were suitable for assessing the fine-scale spatial-temporal change of LULCs in coastal ecosystems in Spain, although complementary assessments and validation methods could increase result validity. Current technological developments will allow improved future assessments in terms of accuracy and resolution.

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.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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