Report C

Sustainable management of coastal areas

How to cite this report:
Oficina de Ciencia y Tecnología del Congreso de los Diputados (Oficina C). Report C. Sustainable management of coastal areas. (2024) www.doi.org/10.57952/cgj0-da61

Researchers, scientists and experts consulted (in alphabetical order)

Bhargava, Radhika[1]**.** Researcher, Center for Nature-Based Solutions, National University of Singapore (NUS), Singapore.

Bordehore Fontanet, César[1]**.** Senior Lecturer, University of Alicante (UA), Spain.

Bujosa Bestard, Ángel[1]**.** Senior Lecturer, University of the Balearic Islands, Spain.

De Andrés García, María[1]**.** Associated Professor, University of Cádiz, Spain.

Desdentado Daroca, Eva[1]**.** Professor, University of Alcalá (UAH), Spain.

Fernández Mora, Àngels[1]**.** Researcher, Coastal Observation and Prediction System of the Balearic Islands (SOCIB), Spain.

García García, Míriam[1]**.** CEO, LANDLAB, SLP Landscape Laboratory. Associate Professor, UPC-DUTP-ETSAB, Spain.

García-Ayllón Veintimilla, Salvador[1]**.** Senior Lecturer, Polytechnic University of Cartagena (UPCT), Spain. Fullbright Visiting Professor, Massachusetts Institute of Technology, United States.

González Pérez, Manuel[1]**.** Researcher, Center for Marine and Food Research (AZTI), Spain.

Guisado-Pintado, Emilia[1]**.** Senior Lecturer and Researcher, University of Seville, Spain.

Lorente Jiménez, Pablo[1]**.** Head of the Network Support and Model Validation Division, Physical Environment Area, Connectivity and Sustainability Subdirectorate, Public Agency, State Ports, Spain.

Mai Huynh, Lam Thi[1]**.** Researcher, University of Tokyo, Japan.

Medina Santamaria, Raúl[1] Director General, Institute of Environmental Hydraulics of Cantabria (IHCantabria), Spain.

Méndez Martínez, Gonzalo[1]**.** Senior Lecturer, University of Vigo (UVigo), Spain.

Nunn, Chloe[1]**.** Consultant and Coordinator of Marine Projects, North Devon UNESCO Biosphere, United Kingdom.

Orfila Förster, Alejandro[1]**.** Researcher, Mediterranean Institute for Advanced Studies (IMEDEA, CSIC-UIB), Spain.

Pagès Fauria, Jordi[1]**.** Researcher Ramón y Cajal, Center for Advanced Studies of Blanes (CEAB-CSIC), Spain.

Piñeiro Juncal, Nerea[1]**.** Postdoctoral researcher, University of Vigo (UVigo), Spain.

Sanz Larruga, Francisco Javier[1]**.** Professor and Director of the Coastal Observatory, University of La Coruña, Spain.

Sardá Borroy, Rafael[1]**.** Principal Researcher, Center for Advanced Studies of Blanes (CEAB-CSIC), Spain.

TEAM C (in alphabetical order)

This report has been led by:

Rüdiger Ortiz-Álvarez. Scientific and Technological Evidence Officer.

The work team is composed of:

Coordination

Ana Elorza. Coordinator of Oficina C at the Spanish Foundation for Science and Technology.

Pedro Peña. Clerk of the General Courts. Director of Studies, Analysis and Publications.

Technical team

Barbara Cosculluela. Clerk of the General Courts. Head of the Department of European Affairs.

Cristina Fernández-García. Communication and Networking Officer.

Maite Iriondo de Hond. Scientific and Technological Evidence Officer.

Sofia Otero. Scientific and Technological Evidence Officer.

Jose L. Roscales. Scientific and Technological Evidence Officer.

Trainee team
Claudia Pereira Domingues. Trainee Evidence Officer.

Nelly Pérez Gutiérrez. Trainee Evidence Officer.

Production method

Reports C are brief documents on subjects chosen by the Bureau of the Congress of Deputies that contextualise and summarise the available scientific evidence on the analysed subject. They provide insights into areas of agreement, disagreement, uncertainties, and ongoing discussions. The preparation process for these reports is based on an exhaustive bibliographical review, complemented by interviews with experts in the field who subsequently conduct two review rounds of the text. Oficina C conducts this process in collaboration with the management team of the Spanish Parliament's Lower House Documentation, Library and Archive service.

To produce this report, Oficina C referenced 305 documents and consulted 20 experts in the field. Of this multidisciplinary group, 40% were from life sciences (biology, ecology, and environmental sciences), 40% from physical sciences and engineering (road, canal, and port engineering, civil and physical engineering), and 30% from social sciences and humanities (geography, applied economics, tourism, sustainability sciences, architecture and urban planning, and law). Additionally, 80% of the experts work in Spanish institutions or centers, while 20% are affiliated with at least one foreign institution.

Oficina C is the editorial supervisor of this report.

[1]Specialists who have also participated in the total or partial review of the report.

Summary C

The report in 5 minutes

Relevance

The Spanish coast is a territory of great ecological and economic value. Along its 7905 kilometres, there are some of the most important natural areas in the country (such as the Delta del Ebro, the Doñana National Park, or the Albufera de Valencia, among many others). In coastal municipalities, around 40% of the population lives and receives significant national and international tourism, which generates employment and a substantial part of GDP. In addition, there are economic activities such as fishing, or port transport. At the legal level, a differentiating element of the Spanish coast from other countries of the European Union is the existence of the public maritime land domain, a strip at the intersection between land and sea protected by the Spanish Constitution, and a state coastal law that regulates its use.

On the coast, there are a number of problems that are well documented and studied by the scientific community. The main one is the erosion that beaches suffer due to the alterations that occur in the natural transportation of sand. Among the causes of the alterations, river dams stand out, which prevent sand from reaching beaches, and coastal barriers (such as ports, dams or buildings) that make it difficult for sediments to travel along the coast. In recent decades, both erosion and floods have increased as a result of rising sea levels and the potential increase in intensity of maritime storms due to climate change. A side effect of beach erosion that has great social relevance is the increased exposure of housing and critical infrastructure to flooding due to extreme meteoro-oceanographic events, as seen with storms Gloria (in 2020) or Nelson (in 2024).

The second problem highlighted by the expert community lies in different forms of coastal degradation, including pollution (the presence of plastics, heavy metals or substances from agriculture and cities), discharges (such as hydrocarbons, wastewater or ballast water), the arrival of invasive species, or the overexploitation of resources (such as fishing boats). Linked to all of this are urban pressure and the tourism model, as well as conflicts derived from the overlap of competencies between different sectors and administrations.

Despite the social and economic relevance of the coast, the resources available for management at the state level are insufficient in the face of present and future challenges. If action is not taken in the short term on the problems described, there could be significant consequences in the medium to long term (over the next 50-75 years), which could affect private property, activities currently carried out on the coast or critical infrastructure. The expert community warns that the phase of diagnosing problems is coming to an end and that it is time to propose disruptive plans and actions that are capable of assuming a certain degree of uncertainty (for example, in estimates of rising sea levels).

Towards an integrated management of coastal areas

The scientific community insists that in order to provide a sustainable and lasting response over time to the problems presented by the coast, there is already a solution: to switch from current sectoral management to integrated coastal zone management (GIZC), as established by the Mediterranean protocol, ratified in 2011 by Spain. At the same time, it asks that the entity responsible for coastal management be provided with adequate material and human resources.

The reason for adopting model is the increasing pressure that coastal areas face due to the urban model, the tourist model and the exploitation of natural resources. Integrated management makes it possible to balance economic development with environmental conservation, promoting a sustainable use of the coastline. Along the same lines, it is important to consider the coastal zone as a whole, the land-sea connection and the multiple stakeholders and administrations involved. The scientific community insists that citizen participation in management decisions must be encouraged and that a long-term vision must be maintained.

Focal point

Within the GIZC model, there is no single solution to the problems presented by the coast. Adaptations to the physical environment are designed to respond to erosion and the effects of climate change. Along these lines, in order to achieve a more resilient coastline and a landscape that can withstand the different pressures to which it is exposed, different types of measures are suitable: structural or engineering, those based on nature and hybrid. In fact, hybrid solutions stand out as those that provide a better adaptation of the physical environment to risks derived from climate change. In any case, the implementation of well-designed adaptations is considered by the scientific community as an opportunity to improve coastal environments. Among other measures, there is the renaturalisation of rivers to increase the transfer of sediments that reach the sea and shape beaches. Thus, it highlights the importance of dunes that dampen the advance of the sea and salt intrusion.

Experts point out that the existence of a public domain is key to being able to adapt properly to rising sea levels and reduce the consequences of coastal flooding. On the other hand, several studies have found that measures must take into account, in addition to pressures and risks, the connection between people and the environment. In other words: we must improve the well-being of the inhabitants who make use of these spaces while they adapt to future pressures. Along the same lines, there are more and more voices among the expert community that advocate a transformation towards tourism models that increase supply linked to the natural values of the territory and demand regulation that solves the negative repercussions of overcrowding, especially during the summer season.

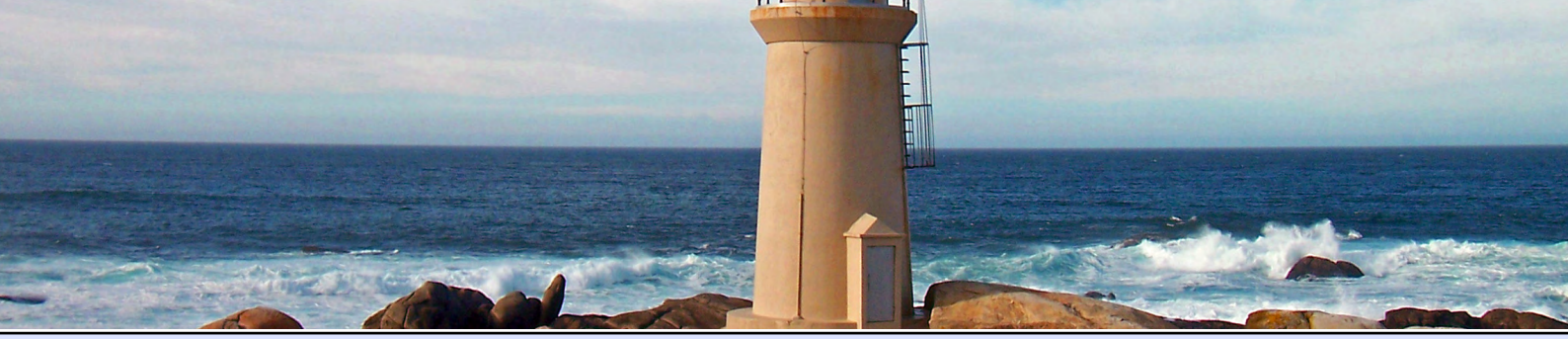

Imagen FOTCIENCIA Faro de Muxía © Arturo Fra Franco

On the horizon

To achieve integrated management that considers the multiple pressures faced by the coast, including possible aggravations resulting from rising sea levels, it is necessary to evaluate whether the legal and governance framework makes this possible. Some analyses carried out by the scientific community indicate that current management is slow and reactive, rather than proactive, making it difficult to implement integrated management. This is partly due to the difficulties posed by the distribution of competence, land-sea interactions, and the social dimension. In this regard, it is worth considering whether almost 40 years after its conception, the current coastal legislation has managed to meet the objectives set out in its preamble: (1) the removal of private enclaves from the public domain in an effective manner that respects the rights of individuals, and (2) environmentally protect the coast. Currently, different disciplines and social movements question whether these objectives are being achieved.

In the future, it has been advocated that the governance framework should aim to protect areas that currently lack environmental safeguards, achieve a better balance between public and private ownership along the coastline, as demanded by social movements, and improve the integration of sectoral areas directly related to this issue, such as port management, tourism, and land use planning.

There are successful and ongoing experiences in different parts of the country that have sought to reorder coastal space to reduce beach use pressure, promotenaturalisation and anticipate future increases in sea level. At the same time, governance formulas including citizen participation have been tested. To achieve this transformation on a large scale, and with a necessary focus on the medium-long term, it is advisable to overcome legal, social and political barriers that may slow it down, while investing in raising awareness and empowering society. Coastal governance spaces should be places where all competent administrations, scientific disciplines, affected economic sectors, and citizens can reimagine their coasts so that they can be enjoyed in the future. All of this would allow for a real and effective implementation of the conceptual framework for integrated coastal zone management.

Sustainable management of coastal areas

Introduction

On the coast, beaches are the spaces that provide the greatest economic value to the country. However, they are being dwarfed by sand deficits. Achieving long-term sustainable management requires consensual governance between the different stakeholders, since static situations are not the rule on the coast.

Spain is a coastal country. This border between the marine and terrestrial environments extends for 7905 kilometres along the Atlantic Ocean and the Mediterranean Sea[1]. Along it, there are different types of environments: from dunes, to estuaries, marshes, interior lagoons or cliffs; but beaches are the spaces that articulate greater economic activity. In 2019, 70.5% of tourism's Gross Domestic Product (GDP) and 62% of direct tourism employment in Spain occurred in destinations known as "sun and sand"[2]. In addition, with data from 2020, 39.2% of the country's population was registered in 480 coastal municipalities[3].

Beyond the direct economic impact, people who live close to a coastal area and, in general, to the natural environment, enjoy benefits in terms of their mental health and well-being[4]. But when the ecosystem that provided benefits is lost, the answer is one of grief, suffering and a sense of loss[5]. This loss is not only emotional, since coastal areas are the spaces that offer the most ecosystem services to society[6]. Some are tangible, such as obtaining food through sustainable fishing, but there are also services for temperature regulation, protection against storms, others that prevent coastal erosion or conserve biodiversity, as well as recreational and tourist values[7–10].

The current situation in most of the Spanish coastal areas is one of great artificialisation: the change of land uses has resulted in the degradation of natural ecosystems[11]. In this context, the main problem with sandy coasts, particularly beaches in the Mediterranean arc, is that they are becoming smaller due to sand deficits in sedimentary dynamics (because the presence of ports, breakwaters, promenades and other coastal and river infrastructures interfere with the transport of sand), but also because of the observed and predicted effects of climate change. In fact, from 1900 to 2018, global average sea level has risen 21 centimeters, and the rate of rise is accelerating[12]. In addition, in recent years there have been intense storms, such as Gloria (2020) or Nelson (2024), which have flooded areas inland. Added to this is the difficulty of adapting and moving the coastline inland naturally in areas with constructed barries[13]. In general, both beaches and other ecosystems in the coastal zone are degraded for additional reasons: pollution, invasive species, intensification of tourism and urban planning, or overexploitation of resources. Along these lines, the scientific community advocates for sustainable solutions and management: durable over time and that do not compromise the capacity for future adaptation[14–16].

In coastal areas, economic activities converge, both on land and at sea, and interests of different parties intersect, which are not always aligned. Management occurs at different levels of public administration with different competencies (**see legal framework section**). The first Coastal Law was approved in 1969[17], in order to organise and plan development, activities, and sectors, as well as solve existing problems and have a joint governance framework with which to make decisions and respond to current and future risks[18]. However, during the 1960s, 1970s and 1980s, the main solution to coastal problems was based on structural rigidity despite being ecosystems in constant movement and evolution[18].

- Coast: From the field of ecology, coast is understood to be the strip at the junction of emerged and submerged lands. By extension, it also refers to both terrestrial and aquatic areas, close to the true coast.
- Dune: A quicksand hill that in deserts and beaches is formed and pushed by the wind. On the coast, they run parallel to each other and are important for protecting the land against the impact of waves during marine storms.
- Estuary: A partially enclosed body of water that forms when fresh water from rivers mixes with saltwater from the sea.
- Marsh: Humid ecosystem with herbaceous plants that grow in water. They are usually linked to estuaries and are important for different groups of animals and plants.
- Coastal municipality: According to Eurostat, municipalities (LAU2) that border the coast or have 50% of their surface area a maximum of 10 kilometers from it.
- Ecosystem services: Benefits that an ecosystem brings to society and that improve people's health, well-being, and quality of life. They result from the very functioning of ecosystems. They are, for example, the provision of clean water, wood or the use of natural spaces or landscapes for recreational or sports purposes.

The expert community indicates that dealing with all these aspects requires management capable of integrating all the stakeholders and sectoral policies present on the coast. It points out that consensual governance is required among all administrations, companies[19], interested associations and the scientific community[20], to achieve sustainable management[21,22]. In the same way, it is critical to convey to society that coastal areas have a dynamic nature on time scales ranging from seasonal cycles, to decades, or centuries, and that static and deterministic situations are an exception[23].

Pressures and their consequences on the coast

The main problems of the Spanish coast are the erosion and retreat of the coastline, as well as the degradation of ecosystems due to pollution, overexploitation of resources or invasive species.

Coastal areas around the world are exposed to pressures, which may have a global origin and reach or are restricted to local and regional aspects[24]. In addition, different pressures can combine and create synergies[25] and, for example, accelerate the erosion of a beach[26], or weaken ecosystems and reduce resilience to other disturbances[27]. According to one of the latest reports on the state of nature in the European Union, only 15% of the marine and terrestrial habitats evaluated are in good condition[28]. In Spain, environmental groups compile a list of the most affected areas of the Spanish coast and indicate possible corrective measures[29]. This report details the pressures that give rise to two of the major problems on the Spanish coast (not the only ones): (1) the erosion and retreat of the coastline, and (2) the degradation of ecosystems due to pollution, overexploitation of resources and invasive species.

Coastline erosion and retreat

Beach erosion has been linked to the anthropisation of the coastline, but it is further exacerbated by rising sea levels and the potential impact of storms, which can lead to flooding, saltwater intrusion, and damage to infrastructure. Erosion affects the maritime-terrestrial public domain, where economic activities converge and which physically borders private properties at risk.

A large number of Spanish sandy coasts are in regression[30,31], have lost their dune systems[32] or need continuous sand supplies in order not to disappear[33]. Beach erosion has been mainly linked to the anthropisation of the coastline and to urban and tourist pressure. In addition, rising sea levels and storm damage can cause floods, salt intrusions, infrastructure damage and ecosystem changes. This erosion reduces physical space on beaches and generates a social and tourist problem[34,35]. For example, in the Basque Country, a retreat of between 10 and 60 metres has been estimated from its beaches[36], in the Ría de Vigo the reduction is 35%[37], and similar values are expected in the rest of the coast. In Spain, several regional strategies against erosion have been developed: for example, in Huelva, El Maresme, Castellón, Valencia or Granada[38]. Numerous municipalities are demanding greater protection of beaches to sustain their tourism or prevent water from reaching private properties, which, after a boundary demarcation, could end up being classified as public land[39,40]. As a palliative measure, there is a high demand for sand by municipalities that base a significant part of their economy on tourism, and they ask the Central State Administration to invest large amounts of money to replace the sand and regenerate their beaches every year and, thus, maintain its entire extension[41,42] (as a reference, the regeneration of the Saler and Garrofera beaches in Valencia in 2022 cost 24 million euros[43], and a report indicates that between 2016 and 2020, nearly 60 million were employed in the total territory[44]). One of the sources of sand comes from the seabed, but its extraction can affect the integrity of ecosystems and reduce their biodiversity[45]; it also comes from quarries and riverbeds. In addition, it is a finite source and is therefore not sustainable in the long term. On the other hand, there are companies that recycle construction waste to convert it into sand[46,47].

· Boundary demarcation: An administrative process that physically delimits which land corresponds to the maritime-terrestrial public domain.

The supply of sand via rivers (the primary source) is disrupted by droughts, agricultural overexploitation, or the presence of dams. Additionally, physical barriers in the sea, such as ports, breakwaters, or groynes, can create sand deficits by interrupting its natural transport along the beaches.

Changes in sedimentary dynamics. The reduction of beaches occurs when more sediment is lost than is gained, and when there are barriers that prevent the movement of those who arrive[13]. In a significant part of the peninsular territory, most of the sand on the beaches comes from rivers, and the rest comes from marine sandbanks or from the erosion of rocky shores (such as cliffs)[13]. This influx of sediments decreases when the flow of the river diminishes, either due to natural causes such as a drought, the agrarian overexploitation of water, or the presence of dams and reservoirs that restrict the flow of sediments[13]. Changes in sedimentary balance make deltas, such as the Ebro, especially sensitive and vulnerable, which is already experiencing problems similar to those projected in other coastal areas 50 years from now[48]. On the other hand, the distribution and movement of sediments on different beaches depends on longitudinal transport. Specifically, on our Mediterranean coast, water currents distribute sand from the north to the south, so a barrier (such as a port, a dam or a breakwater) stops transport: it causes sand to accumulate in its northern part and generates a deficit in the south[49]. On the Cantabrian and Atlantic coast of Galicia, beaches are usually embedded and do not face this issue. For its part, the urbanisation of the coastline has eliminated dune ridges and prevents the formation of new dunes, which are the natural sand reservoir of the beaches and would allow them to recover naturally [13]. In short: the channeling of rivers, the construction of barriers and excessive urban planning have had an impact on the natural dynamics for the formation of beaches and contribute to their disappearance.

Spain has experienced urban and residential development that has neglected ecological and cultural considerations, replacing ecosystems with hard infrastructures, many linked to tourism.

Urban and tourist pressure. Spain has experienced significant urban development in coastal areas since the 1950s[50], which has routinely neglected ecological, landscape, urban quality or cultural considerations[51]. The extensive use of land, the construction of infrastructures and the increase in population, has led to the replacement of natural systems with "hard" infrastructures, such as promenades, walls, piers, ports or housing linked to tourism (due to housing demand[52]). This pressure has led to the existence of urbanised beaches that, unlike natural ones, are usually surrounded by infrastructure and cannot move inland naturally[53,54]. It has also led to a fragmentation and degradation of habitats[55], a reduction in biodiversity[56] and an increase in demand for services, including water, with the consequent overexploitation and alteration of their physico-chemical characteristics, in particular at the heights ofthe holiday season[57].

Rising sea levels increase beach erosion, harm economic assets and activities and modify the boundaries of the maritime-terrestrial public domain.

Sea level rise. The rise in mean sea level, combined with extreme metocean events (such as intense storms or strong waves), can cause coastal flooding in exposed and vulnerable areas where it did not occur before and exacerbate erosion. Sea level rise is a direct consequence of climate change, through two different mechanisms. First, due to thermal expansion: warmer water takes up more volume[61]. Greenhouse gases emitted by human activity have increased global ocean surface temperature[62] (the increase in CO_2 causes 70% of global warming due to its capacity to absorb and emit infrared radiation, that is, heat, which becomes trapped on planet[63]). Second, the amount of water in the ocean increases as polar ice melts on land and glaciers[61] (**Key point 1**). Its impact on the coastline occurs at several levels: (1) economic, due to its participation in beach erosion and deterioration of infrastructure (roads, train lines, power lines, treatment plants, etc.) and businesses associated with tourism; (2) urban planning, by affecting the limits of the maritime-terrestrial public domain (DPMT) and, therefore, putting properties at risk of expropriation; and (3) ecological, by modifying the conditions of the coastal system in which different species live. Currently, there are different rates of increase, more or less intense, for the year 2100 (**Key point 1).**

· Longitudinal transport: Movement of sediments along the coastline due to currents and waves and which determines their morphodynamic state. This transport can be interrupted by physical barriers.

Sea level has risen 0.21 meters since 1900 and the rate of rise is accelerating, due to ocean warming and polar and glacial melting. Abrupt increases are possible, although their prediction is subject to uncertainty.

Key point 1. How much will the sea level rise between now and 2100?

There is scientific consensus that the average sea level is rising worldwide and will continue to do so. The uncertainty lies in the 'how much´.

Increase estimates. The rate of climb is accelerating continuously: it has gone from an average increase of 1.3 mm/year (period 1900-1971) to 3.7 mm/year (2006-2018)[12.64]. Since 1900, the sea level has risen by 0.21 meters, and the predictions of the Intergovernmental Panel on Climate Change (known by the acronym in English IPCC) for the year 2100 predict a rise (compared to the average sea level of 1995-2014) of 0.28-0.55 m in the most optimistic scenario (SSP1-1.9), to 0.63-1.02 m in the most pessimistic scenario (SSP5-8.5)[12]. In a scenario where sea levels rise by one metre, the risks of flooding and erosion would increase in, for example, important coastal cities such as Huelva, Santander, infrastructures such as El Prat Airport, or protected areas such as the Doñana [65] National Park.

Why will the sea level continue to rise? Even in an optimistic scenario of the cessation of greenhouse gas emissions, the ocean surface temperature will take several centuries to decrease. The reason is that the planet cannot immediately emit the extra energy absorbed from the Sun. In other words, the energy balance of absorbed solar energy and energy radiated back to space has a high persistence[66]. This balance decreases due to the absorption of excess atmospheric CO_2 by the oceans and land[66], but this process occurs on a scale that exceeds the lifespan of a person[67]. An attempt is being made to compensate for CO_2 emissions with intentional removal (for example, with technology), although it has been proven that avoiding the emission is more effective than subsequent removal[68].

Uncertainty and possible disruptions. There are studies that suggest that contemplating a low-emission scenario is unrealistic, and that the effect of climate change could accelerate more than expected[69]. The plans and actions that are designed must integrate uncertainty into each phase of execution. Given the possibility of a rapid and irreversible thaw of icy areas (specifically, of the ice masses of Greenland, West Antarctica, or the permafrost of the Arctic[70.71]), a rise of up to 2.3 metres is estimated by 2100, and 5 metres for 2150[72-75]. In addition, in 2023, the global sea temperature was higher than all[76] mathematical models predicted. Considering these scenarios, as well as other disruptive climate processes, such as a possible change in ocean currents[77], is important in coastal risk management and long-term adaptation, especially in densely populated coastal areas[78].

An increase in the intensity of the storms is expected, but not in their frequency. This would be detrimental in highly urbanised areas and would contribute to the retreat of beaches.

Extreme meteoro-oceanographic events. Storms and DANAs are common on the Spanish coast, which are associated with intense rainfall and strong waves[79]. These events have a strong impact on beach erosion and can move large amounts of sand offshore. On the other hand, rivers can also mobilise sand that is then distributed on the beaches. The problem worsens in highly urbanised areas, where the original hydrographic network[79] has been lost and the impact of possible floods (on beaches or infrastructure) is very high[79.80]. The consequences of the 2014 storms in Cantabrian[81] stand out; storm Gloria in January 2020, on the Mediterranean coast, which eroded numerous beaches and affected[82] promenades (although it also mobilised large amount of sand from the river networks that allowed it, and there are areas that have not regressed since then, such as in El Maresme Alto, in Catalonia), or storm Nelson in 2024, on the Catalan and Valencian coasts. Regarding future predictions, according to the IPCC AR6, an increase in the frequency of these types of events is not expected, but they can manifest themselves with a higher wave[83] and, in general, with greater intensity[84.85]. Together, the sum of sea level rise and storms increases the extent at risk of flooding. In the port area, the Meteorological and Oceanographic Support System of the Port Authority (SAMOA) allows monitoring and predicting extreme wave conditions (among other variables) and if there is a possibility of levees being exceeded, which would compromise the efficiency and safety of port operations. Framed within the SAMOA initiative, the Environmental Scorecard (CMA) makes it possible to establish customised alert thresholds for each port based on its maritime

· DANA: Isolated Depression at High Levels. Formerly known as “cold drop”.
· IPCC AR6: From the acronym of the English Intergovernmental Panel on Climate Change, corresponding to the sixth Assessment Report, published in 2021.

climate (chracterised by observations provided by various measurement networks[86]). These facilitate decision-making and effective and sustainable environmental management in the face of adverse meteoro-oceanographic situations, in order to improve the competitiveness of the Spanish port system. Finally, although they are not common in Spain, there is a state plan for civil protection against the risk of tsunamis[87].

Other forms of degradation of ecosystems and ecosystem services

Other phenomena that degrade coastal ecosystems include pollution, discharges, overfishing or invasive species.

In addition to erosion, there are many other phenomena that can degrade coastal ecosystems and jeopardise the benefits that people derive from them, which are called ecosystem services. These processes are very varied and, in this report, four of them are addressed: different forms of pollution, discharges, overfishing, and invasive species.

There is exposure to heavy metals, oils, hydrocarbons, plastics, excess nutrients or noise pollution, among others.

Contamination. The coast is exposed to different types of pollutants: heavy metals, oils and hydrocarbons, plastics, excess nutrients, and noise pollution, among others. Microplastics are fragments and compounds that can enter food and be ingested by people[88.89]. Its sources include plastic bags and bottles, fishing gear or non-biodegradable polyester sanitary wipes[90,91.] With regard to pollutants from agricultural areas[92], industrial or urban, these can generate excess nutrients in aquatic ecosystems, increase primary production and trigger different problems: algal blooms (which may or may not be toxic), turbidity, lack of light or hypoxia (low oxygen conditions)[93]. All of this causes habitat degradation, loss of species, and changes in biogeochemical cycles[94]. Although numerous European directives have succeeded in reducing nutrient inputs to the sea[95–99], these are not enough to improve the ecological structure and function of many coastal areas[100]. This generates a high expense for municipalities that must purify water with excess nitrates[101]. Finally, passenger container ships and oil tankers generate noise at sea and on the coast[102], which can affect the ability of marine species to communicate, causing behavioral changes or physical damage, including stranded or dead whales [103.] The expert community suggests moving towards a global regulation of underwater noise that addresses its impact and its interaction with other coastal pressures, for which a European report has listed different priority actions[104].

Oil and oil pipeline discharges have fallen substantially over the past decade.

Discharges. Contaminants can take the form of spills. The activity of ports and cruise ships and passengers can release wastewater, ballast water with polluting elements and potentially invasive species, or antifouling compounds, among others[105]. In addition, wastewater discharges with poor treatment, or from undersea effluents with low maintenance[106], provide microbiological contaminants (with an effect on water quality) as well as nutrients and organic matter[107]. Along with brine discharges from desalination plants, these can have an impact on[108,109] marine ecosystems (such as seagrass meadows, see **Key point 2**). The recovery of the Bilbao estuary should be highlighted as an example of good practice in an extremely degraded space [110,111]. On the other hand, discharges from oil pipelines and oil tankers in coastal areas have decreased by ten, globally in the last decade[112], although hydrocarbon discharges can still occur, such as the one that affected the Albufera de Valencia[113] in 2024. The state has a plan against oil pollution, the State Plan for the Protection of the Seashore (order AAA/702/2014), with a sensitivity atlas and a vulnerability and risk analysis[114]. The public agency State Ports has coordinated, within the framework of the SAMOA initiative, the development of mathematical models to predict the trajectory of possible accidental discharges of hydrocarbons inside ports and at their anchorages. These models, integrated into the CMA of each port, facilitate consensual and effective decision-making in the face of this type of environmental incident[86].

Marine areas under strict protection would improve fishing in surrounding areas, serving as a breeding ground for species.

Fishing, aquaculture and shellfish. Overfishing leads to a reduction in the animal population, can damage the habitat (as with trawling) and causes damage to the entire marine ecosystem[115]. Therefore, it affects the performance of the fisheries themselves[116]. The scientific community has demonstrated that protecting marine areas (and not fishing in them) favors the regional fishing industry, acting as a breeding ground for fish, which move to areas where fishing is allowed[117,118]. The European Union and Spain have committed themselves, through the "Biodiversity Strategy for 2030", to protect at least 30% of the seas in 2023 and that 10% enjoy strict protection (i.e., that extractive activities are not allowed)[119]. This 10% may not be enough to maximise fish production[120]. However, EU countries (including Spain) barely achieve 1% of strict protection[121]. On the other hand, it has been quantified that 90% of protected areas belonging to the Natura 2000 Network have experienced trawling, especially on the coast of southern Almería[122]. Environmental associations are promoting the achievement of the commitments made[123,124], which would have a positive economic impact for fishermen (since protection allows fish stocks to recover), in addition to significant benefits for marine ecosystems[125]. In addition, the EU has approved a plan in 2024 for member States to implement sustainable fisheries management based on protecting the ecosystem, reducing bycatch and increasing the integrity of the seabed[126]. With regard to shellfish, which accounts for around 10% of GDP in Galicia, there is a decline in some species as a result of overexploitation, poaching, habitat degradation, pollution, acidification[127] and the warming of the sea. This has a strong socio-economic impact[26].

Invasive species have impacts on the fishing and tourism sectors. In Spain, the problem of the invasive algae *Ragulopteryx* okamurae stands out, which grows very quickly.

Invasive species. These affect the ecosystem services provided by other[128] species, and can impact the fishing or tourism sectors[129]. The introduction and dispersion of non-native species is increasing due to maritime transport (in ballast waters) and aquaculture[130], as well as changes in habitability as water warms[131]. The "hard" infrastructures on the coast also make it easier for these[132-134] species to disperse and take root. The Mediterranean Sea has been the most affected by the introduction of exotic species through the Suez Canal (which connects to the Red Sea)[135]. Among them is the Japanese-derived alga *Ragulopteryx okamurae,* which has a great competitive growth capacity[128]. Spain has a specific control strategy for this species[136], although its complete eradication is considered to be very complicated to impossible. Some voices suggest that possible initiatives to valorise their remains can be addressed as long as their perpetuation in the environment is not facilitated[137]. The entire problem is articulated through a dynamic Spanish catalog of invasive alien species, determined by Royal Decree 630/2013[138], which is monitored by regional institutions that issue detailed reports, such as in the Balearic Sea Report[139]. In addition, citizen science initiatives, such as Observers of the Sea, contribute to the detection of species of interest in the sea and the coast[140,141].

Monitoring of coastal pressures and conditions

Obtaining high-quality, high-resolution data from the coastal zone is the first step in decision-making based on scientific evidence.

Obtaining high-quality, high-resolution data from the coastal zone is the first step in decision-making based on scientific evidence. Surveillance provides information on morphological changes on the coast and the sea, as well as on water quality and different pressures. These data make it possible to create predictive systems based on mathematical models that provide information in the short term (for example, anticipating wave conditions days in advance), but also in the medium-long term (such as with regard to climate change).

- Red Natura 2000: European network composed of Sites of Community Importance, Special Conservation Zones and Special Protection Areas for Birds. These spaces will be considered protected areas, with the specific name of Natura 2000 Network protected areas. In accordance with Law 42/2007, of December 13, on Natural Heritage and Biodiversity, they must have planning tools.
- Acidification: A phenomenon that involves a decrease in the pH of seawater due to the absorption of atmospheric carbon dioxide. This process has significant implications for marine ecosystems, such as calcifying organisms.

In the public administration, measurement networks operated by State Ports stand out, distributed along the coastline. They include buoys, tide gauges, weather stations, and high-frequency radars (which are located on the shoreline and are capable of providing data on surface sea currents and waves, among other parameters[142]). In addition to applications for the general public, measurement networks support ports within the framework of the SAMOA system to make operational decisions that guarantee safety and sustainable environmental management in the port environment[86].

On the other hand, information on the state of the coast can also be obtained through videometry[143,144] (camera system for studying the evolution of the coastline and state of the beaches), satellites such as the Sentinel-3 of the European *Copernicus program (high-resolution information on the state of the coastline or water quality*[145,146]), drones, small plane flights, and observation techniques with LIDAR that allow 3D models of the coast[147]. In addition, coastal erosion monitoring can be carried out through citizen science initiatives such as *CoastSnap*[148,149], a worldwide project that allows beach users to record images with their mobile phones at low-cost fixed stations. This initiative raises public awareness of coastal erosion while obtaining high-resolution data from[150] Spanish beaches.

Sustainable adaptation of a dynamic system

The expert community points out that, in order to achieve sustainability in the medium and long term, it is necessary to carry out integrated coastal zone management (GIZC).

A coastline adapted to withstand the pressures to which it is exposed requires considering all the present socio-ecological dimensions, assuming their interconnection, and balancing them simultaneously[23]. The expert community points out that in order to achieve coastal sustainability, it is necessary to carry out integrated coastal zone management (GIZC, by its Spanish initials)[151]. This is a medium and long-term knowledge-based approach that seeks to balance environmental, economic, cultural and recreational objectives, within the limits imposed by the natural dynamics of a place[152]. In short, it promotes the sustainability of coastal areas through the participation and cooperation of the parties involved in the field, and defines actions to achieve the agreed objectives. Each solution must be adapted to local particularities, but taking into account the possible impact of measures at the regional level (for example, the presence of a physical barrier for sand to accumulate on a beach could deprive an adjacent municipality of sand; or certain agricultural practices can contaminate a nearby body of water, as is the case in the Mar Menor)[152].

The European Union has made these principles explicit as recommendations since 2002[152], and indicates that measures must have the support and participation of all local, regional and state administrative bodies. It also points out that different instruments should be used together to facilitate coherence between sectoral policy objectives, planning and, ultimately, management. Specifically, for coastal areas of the Mediterranean, since 2011 there has been an official international protocol relating to integrated management, signed by Spain, the EU and other surrounding countries[153,154]. There are voices in the scientific community that observe that the practical application of this protocol in Spain is scarce[155], but the strategy designed for the Mar Menor and its environment[156] could be highlighted, in which a process was carried out with the public participation of all the actors of society involved and considering a large coastal area, in which pressures from land and sea could be quantified to evaluate impacts[157].

· Integrated coastal zone management: It can be defined as the process legitimised through a public policy, with a technical-scientific basis but which takes into account traditional knowledge, aimed at the administration of common goods and public interests; which is oriented to decision-making to obtain the best and most equitable social and economic benefit from the services of coastal and marine ecosystems, taking special care to conserve natural capital, cultural heritage and landscape; while facing the risks and threats that loom over people, assets or resources.

On the other hand, digital twins of the coast are being developed to incorporate all processes, quantify uncertainties and possibilities, and facilitate decision-making[158]. The chosen measures should have adaptive potential and self-organization capacity (both social and ecological)[23]. Finally, it has been highlighted that there is a need to train managers and decision-makers on potential solutions, taking into account long-term coastal dynamics, as implementing adaptation measures will become more challenging as sea levels continue to rise[159].

Land use planning and adaptive urbanism

The scientific community advocates for shifting from traditional civil engineering to a comprehensive landscape restoration approach, taking into account current risks and future projections.

Urban development on the coast, which began in the 1950s, was largely done without taking into account the natural dynamics of the coast, which has increased vulnerability to different pressures. It has been quantified that 80% of the urban areas on the coast contain ecosystems that could benefit from effective integrated management[160]. Currently, there are voices from urban planning and landscape design that advocate a change of scale: from traditional civil works, to a reconstruction of the landscape as a whole[23]; and that at the same time consider current risks and forecasts of possible long-term threats (for example, rising sea levels), and the governance framework. It must be considered that urban planning powers are held by autonomous communities and municipalities, but the DPMT is public and management is the responsibility of the State, although at the ecological and coastal dynamic levels both parts are connected[161]. The objective is to achieve the resilience of the entire system, by integrating into coastal planning the urban elements already present in the planned designs, actions and structures[23].

To achieve a resilient coastline, multiscale thinking (from the neighborhood to the regional level) is necessary, as well as adaptive and locally-based management.

Resilient landscape design. The general principles of resilience must be the basis for building a landscape that protects against climate pressures, reduces the impacts of rising sea levels and extreme events and, at the same time, improves biodiversity and the health of inhabitants[23,162]. This requires thinking at multiple scales simultaneously: from the region to neighborhood[23]. Numerical modeling to determine the effect of rising sea levels makes it possible to quantify local risk and uncertainty, helping in landscape planning and defining the actions to be taken in adaptive management[163]. There are studies that include social participation through local-based management, as a tool to understand the values, interests, and needs of the inhabitants of each place, and to achieve greater social acceptance of the solutions adopted[164–166].

If the shoreline changes, it may happen that private properties come into contact with water and become in the public domain. There is intense social unrest in the affected areas.

Private property on the waterfront. Urban areas close to water are more exposed to potential flooding and are susceptible to several adaptation approaches: defense, accommodation, strategic relocation or risk reduction[167]. The strip most immediate to the coastline is in the public domain and belongs to the State. These limits are defined by state coastal legislation[168,169]. In the event of a retreat of the coastline, it may happen that private properties come into contact with water and become within the public domain through the administrative delimitation procedure[170] and, therefore, be susceptible to a change of ownership. This, together with the loss of some beaches, generates social alarm[171]. Urban planning adapted to forecasts of sea level rise must be linked to collective action and ensure the fairness of its application[172].

- Digital twins: Virtual model of an object or system that is updated from massive data. It can simulate from one cell a computer system, an ecosystem, or an entire city. They are used to perform simulations and study the behavior of such a system and then adapt the solutions to the real world.
- Self-organisation: A process in which order or coordination is established based on the local interactions of the components of an initially disordered system, which occurs spontaneously, without the control of external or internal agents.
- Resilience: Within the framework of land use planning, resilience is the ability to resist pressure and to return to a previous state. It is based on the principles of diversity, redundancy, network connectivity, modularity and adaptability.
- Adaptive management: Type of management in which a cycle is carried out and the situation and the resulting scenario are observed, actions are taken again, and the observed changes are responded to. Then, the situation is re-evaluated and actions are taken again, applying the lessons learned. In other words, it takes into account the dynamic nature of the coastal system.
- Local-based management: Management that considers how different groups of people identify with coastal spaces as "places" that have their values and meanings, beyond simply being "spaces". There are tools and techniques that can obtain information from the local population to support different coastal management strategies.

Types of adaptation measures

There are engineering, nature-based, or hybrid measures.

To achieve a more resilient coastline and a landscape that can withstand the different pressures to which it is exposed, different types of measures are suitable: structural or engineering (also known as' hard 'solutions, or' gray 'infrastructure), those based on nature, and hybrid between both types. A meta-analysis found that combining nature-based and engineering-based solutions offered a better adaptation to pressures derived from climate change, particularly in low or medium disaster risk[173], as is the case of Spain (Japan being, for example, a country at high risk, due to its exposure to tsunamis). The measures detailed below can be implemented to maintain the coastline, even to advance it, or to allow for controlled relocation or retreat, an approach that is the basis of management in the United Kingdom[174], and which has also been contemplated in France[175]. This model is compatible with voices from the scientific community that speak of areas that must be protected (slightly altered), areas that can be brought to a desirable state (and therefore adapted), and others that are too altered, which would not be a priority.

Classic solutions based on steel and cement can be combined with nature-based solutions and become hybrid solutions.

Structural or engineering solutions. These are the traditional man-made infrastructures, based on stone, steel and concrete[176], that protect the coast from floods and try to reduce the force of the waves. In many locations, the operational life of some maritime retaining walls has been extended in order to keep the coastline[177] stable. However, concerns about ecological impacts[178] and medium-term sustainability[179] have led to more strategic approaches[42,180,181.] Although they may be limited by the dynamic nature of the pressures and risks to which the coast[176] is exposed, they can go from being hard to semi-hard structures, or from fixed to mobile. By becoming multifunctional, they can be integrated with nature-based solutions and become hybrid solutions[23]. An example is the so-called artificial living reefs that mitigate waves and, at the same time, due to the type of material, their shapes and arrangement of the pieces, have served as a habitat for marine life and improved biodiversity[182].

They function as part of natural ecosystems and can reduce the impact of climate pressures. Examples are dune systems, wetlands or artificial reefs.

Nature-based solutions. They are designed to work with natural processes, and provide multiple ecosystem and coastal protection benefits. They would function analogous to natural ecosystems without human intervention in terms of their resilience and associated biodiversity[183]. They have gained momentum in Europe since the 1990s and especially between 2005 and 2015, especially in wetlands, due to their capacity to be sustainable and resilient[184]. Its effectiveness will depend on the magnitude of the climatic pressures and social reality of the area. Therefore, it is important to consider and manage uncertainty through a variety of strategic options[185]. For example, the restoration (with criteria based on the functioning of nature) of riverbeds and associated wetlands reduces the effects of floods in municipalities that have an outlet[186] and improves natural sand supplies. The existence of wetlands mitigates floods[187], reduces wave energy[188.189] and is considered an economically viable option in the face of an intermediate rise in sea level[190,191]. Along with dunes, wetlands are a good natural solution to protect against[192] floods and absorb wave energy[193,194]. Although not always possible, removing physical barriers so that dunes can move inland allows them to maintain their protective function when sea level rises[195]. It should be noted that the ecological restoration of these systems must take into account that young ecosystems are also optimal for many species[196]. On the other hand, seagrass beds provide a large number of benefits, including protection against waves **(Key point 2).**

Seagrass conservation is a solution to reduce wave strength. They are particularly effective in the face of major storms and extreme weather events.

Key point 2. Conservation and restoration of seagrass meadows.

The existence of underwater grasslands is a nature-based solution. It has been observed that its presence reduces the strength of the waves and that even low-lying meadows can reduce beach erosion by up to three times as much as three times as a result of wave[197]. They are particularly effective in the face of large storms and extreme meteoro-oceanographic events[198,199]. On the Atlantic-Cantabrian border, they stabilise coastal wetlands, helping sedimentation to adapt to the rise of average sea level[200]. In addition, these ecosystems provide other benefits: they are a habitat for species of fish and other marine animals, they provide food security to coastal populations and can accumulate and eliminate microplastics[201] and heavy metals[202] from the water column. Thus, if a disturbance degrades grasslands, accumulated pollutants could be released[203]. Among its threats are their physical removal by anchors from boats (recreational boats can damage them very easily)[204,205], some shellfish practices and, until the 1980s, trawling less than 50 metres deep[206] (banned since 1975[207]). They are also affected by poor water quality derived from nutrient discharges from agriculture or aquaculture[208,209], or from undersized treatment plants), while the regeneration of beaches with very fine sediment sand can slow down or prevent their recovery[210]. This is when grasslands are most vulnerable to marine heatwaves[211]. It should be noted that, in areas of the Mediterranean Sea, the degradation of *Posidonia oceanic meadows seems to be slowing down*[212], in part thanks to improvements in water quality[213]. On the other hand, in the Atlantic Ocean, grasslands are recovering[214]. Even so, full recovery is very slow and can take anywhere from a[215] decade to almost 100 years, due to its low growth rate[206]. For this reason, the scientific community insists on the importance of protecting and conserving existing grasslands, in addition to planning long-term restoration.

The best strategy for seagrass meadows is their conservation, as they grow slowly. At present, its ability to compensate for $_{CO2}$ already emitted is debated.

Blue carbon ecosystems as a sink for emissions. Carbon, captured and stored in coastal ecosystems with vegetation, such as seagrass meadows or[216] marshes, is called "blue carbon". Climate change mitigation strategies require: (1) reduce CO_2 emissions from fossil fuels, (2) technological solutions for the removal of atmospheric CO_2[217,218], whose effectiveness and risks are still very unknown[219], and (3) expand ecosystems that accumulate carbon for long periods, while evaluating other options. In this context, it has been estimated that the restoration of coastal ecosystems could remove approximately 3% of annual global emissions until 2030 (compared to the average of emissions in 2019 and 2020)[216]. Despite scientific and media interest, a complete restoration is slow and has many difficulties[216]. So much so, that the ability to achieve this 3% compensation of emissions has been questioned[220]. In addition, voices within the scientific community report that there is a mismatch between the time scale at which emissions are made (faster) and at which they could be removed through ecosystems (slower)[221]. Therefore, the restoration or protection of these ecosystems can never replace strategies to reduce emissions. The great advantage is that their protection can stabilise the carbon already stored in the sediment and prevent the emission of more CO_2 into the atmosphere, even if they do not absorb more than they already have accumulated[221].

Towards a more sustainable tourism

There are voices that advocate a transformation towards tourism models that increase related supply and that protect the natural values of the territory.

In the coming years and in accordance with current trends, changes in demand are already being observed due to climate change. At the same time, the sector is demanding to protect its economic activities, especially in those businesses linked to sun and beach tourism[222]. There are more and more voices calling for a transformation towards tourism models that increase supply linked to and respectful of the natural values of the territory. Meanwhile, the populations receiving seasonal tourism, especially in the Canary and Balearic Islands, are showing their discomfort about the negative repercussions of the overcrowding they receive during the summer season[223,224].

A lower tourist influx is being observed in the coastal provinces of southern Spain, to the benefit of the cooler provinces in the north.

Effect of climate change on tourist flow. Increases in temperature and humidity cause loss of comfort and, as they rise, they can endanger human health and increase the mortality rate due to heat. Faced with a global temperature increase of 2ºC, some areas of Europe, including Spain, could approach the thermal limits of human survival[225]. This effect seems more serious in some subtropical coastal locations where they are already reporting wet bulb temperatures that reach this limit[226]. In Spain, this level is not expected to be reached in the short term, but a variation in seasonal volume is expected, with a possible increase in tourism in spring and autumn and a decrease in summer due to excessive heat, especially in the Mediterranean region[227]. Another pattern that is already being observed, and which is expected to increase, is that the coastal provinces of southern Spain lose attractiveness due to an increase in temperature that tourists consider to be above their comfort zone[228]. Thus, economic losses (as its market share decreases) are expected during summer[228], with a benefit for the colder provinces of the north and a decrease in travel to the provinces of the south[229]. This requires a series of short-term adaptive measures.

Tourists are willing to pay fees to finance public policies that reduce the effects of climate change in coastal destinations.

Adaptive measures. Adaptation can benefit from the analysis of preferences to design policies that maximise social welfare and thus recover the expected losses in the share of the travel market[228]. Among the many classic factors that weigh on the decision of one destination or another (such as the price, the offer of activities, etc.), in recent years, the decrease in the surface area of[230] beaches and the increase in heat, in particular among foreign tourists[231], have been gaining weight. In addition, some studies indicate that tourists are willing to pay fees to finance public policies that reduce the impacts of tourism itself and climate change on coastal destinations, and that they value economically the environmental preservation of tourist areas[35]. At the same time, they are willing to reduce and offset their carbon footprint in [232] destinations. At the level of strategic governance, the "National Plan for Adaptation to Climate Change (PNACC)"[233] indicates the need to integrate adaptation to climate change into plans, programs and strategies in the field of tourism, including the "Sustainable Tourism Strategy of Spain 2030", still under development[234].

Sustainable tourism takes into account the environmental load capacity, physical space and climatic conditions of destinations.

Promotion of sustainable tourism. As mentioned in the PNACC, sustainable tourism is one that takes into account the environmental load capacity, physical space and the climatic conditions of[233] destinations. The benefits are valid both for places that are already exposed to high seasonal pressure, such as Andalusia[235], and for areas that may see an increase in demand (northern Spain). Some examples of measures are to promote a type of tourist who values nature, hiking or cycling. In the same way, it is proposed to promote green routes in less hot areas, link tourism activity to environmental protection projects[236] or establish a quota system, such as the one existing in the archipelago of the Cies[237] Islands. On the other hand, it is worth considering increasing waste management and water purification capacity in situations where the population doubles or triples, to reduce pollution and pressure on the environment, as well as pressure on basic services and housing prices[238,239]. In this regard, some organizations and social movements in the Canary Islands demand that the purchase of housing by foreigners be limited and regulated, an ecotax, and a review of the economic model of the[224] islands. Part of the scientific community points out the need for greater multidisciplinary research on the impacts of tourism when making strategic management decisions and in society.

· Wet bulb temperature: A temperature that considers relative humidity. It is considered that 35ºC with maximum humidity is the physiological survival limit for people (this limit rises to 40ºC with a relative humidity of 75%).

Port sector

State ports are exposed to pressures derived from climate change and, for this reason, they have developed adaptation strategies. Port demand is expected to increase by 2050.

Spain has 46 ports of general interest managed by 28 port authorities, which constitute the state public port domain, in addition to others of regional competence (small in size, such as marina). Ports are critical to the Spanish economy, since 60% of exports and 85% of imports pass through them, contributing to 1.1% of Spanish GDP[240]. But rising sea levels combined with an increase in the intensity of extreme meteoro-oceanographic events threaten the operability of ports, which could significantly reduce current operational capacity, especially after 2070, if adaptation measures are not taken[241]. For this reason, the public body of State Ports has published specific reports on the vulnerability of its ports, with information that transcends its sector and is of interest for the sustainable management of the entire coast[240].

European ports are at risk of being affected by extreme sea level variations, with an increase of more than 25% in the load affected by the high warming scenario (IPCC scenario RCP8.5) compared to the intermediate scenario (RCP4.5)[242]. On the other hand, a significant increase in demand for port activity areas is expected by 2050, which will require the construction of new areas and the adaptation of existing ones to maintain current levels of operation in the face of rising sea levels[243]. The number of ports affected by the overflow of waves over the dikes and the economic impact of these events will increase as sea level rises, although significant savings can be achieved in adaptation measures if a minimum level of damage is allowed, as shown by a study in Catalonia[244]. In addition, State Ports has a[245] sustainability strategy that includes formulas to reduce waste, pollution and waste discharges derived from port activity[246]. In addition to the Strategic Framework for the port system of general interest (Order TMA/1014/2022)[247], the Autonomous communities. may propose additional actions in their area of competence[248].

Legal and governace frameword of the coast

Coastal protection requires an integrated vision, but competencies are fragmented between different administrations.

Legal regulation requires an informed view of science, human rights and the environment. Although coastal protection requires a comprehensive perspective and vision, related competencies are very fragmented among different public administrations[249] (**Key point 3**). Comprehensive management must consider legislation and governance at the state, regional and municipal levels, in land and coastal planning[249]. However, the distribution of competence, land-sea interactions and the social dimension make derivative management slow and reactive rather than proactive; in other words, it hinders the real implementation of integrated management[155]. Legal scholars of the subject indicate that it is necessary to achieve a culture of administrative cooperation in the face of a compartmentalised vision of competencies[250].

Coastal law

The objectives of the coastal law have not been effectively met, with regard to the elimination of private enclaves from the public domain, and with regard to environmental protection.

Limitations of the Coastal Act. The Coastal Act of 1988[169], amended in 2013[252], responded to the constitutional order. Its preamble summarises two main objectives: (1) eliminate private enclaves from the public domain effectively and with respect for the rights of individuals, and (2) environmentally protect the coast[270]. However, from different disciplines (including the legal sphere, social movements and various associations[271]), it is indicated that these objectives have not yet been effectively met. The 2013 reform valued the coastline from an economic perspective, but the "protection and sustainable use of the coastline" were not the focus of the new[272] legislation. In addition, it solved some problems arising from the application of the Coastal Law through exceptions (some population centers were excluded from the DPMT, and concessions of private property on public land were extended)[272]. With its virtues and deficiencies, this regulatory framework was a milestone in the relationship between the citizen and the Administration with the coast[273].

The coast contains the only category of public domain assets mentioned by the Spanish Constitution of 1978. The governance framework is one of a wide division of competence, with numerous sectoral policies in different departments.

Key point 3. What is the governance framework in coastal areas?

Legal system. The coasts contain the only category of public domain assets directly mentioned by the Spanish Constitution of 1978: the "Maritime-Terrestrial Public Domain" (DPMT). This includes the seashore (beaches, dunes and rocky coastline affected by tides and wave splashes), the territorial sea and inland waters, as well as the natural resources of the economic zone and the continental shelf[168]. The DPMT is specified by Law 22/1988, of July 28, on Coasts[169], and Royal Decree 876/2014, of October 10, which approves the General Coastal Regulation[251]. In addition, the State is vested with the competence to enact basic legislation on environmental protection (which the autonomous communities can expand and manage). On the other hand, the Autonomous communities., according to their statutes of autonomy, and municipalities have powers and legislation in land planning, urban planning, public works or ports, as established by the constitution and summarised in Law 2/2013, of 29 May, on the protection of the coast[252], which implies management outside the DPMT. These competencies allow CCs to. AA. manage strips of 100 and 500 metres inland, called "protective easement strip" and "area of influence", in which works and buildings are limited and architectural screens must be avoided. Also, some Autonomous communities. have transferred functions and services from the General State Administration in matters of coastal planning and management, such as Canary Islands[253], Balearic Islands[254], Andalusia[255], Galicia[256,257] or Catalonia [58]. On the other hand, a ruling of the constitutional court in 2024 with respect to Galician law (STC 68/2024)[259] includes the function of granting authorizations for the use and occupation of the DPMT in the exclusive competence over land and coastal planning, while keeping state powers unaffected if such authorizations or the approved plan fail to comply with coastal legislation.

Sectorial legislation. There are numerous activities that take place on the coast that have their specific legislation or management instruments. With regard to environmental protection, stand out Law 42/2007, of December 13, on Natural Heritage and Biodiversity[260], which regulates protected areas, and Law 21/2013, of December 9, on Environmental Assessment[261], which regulates plans, programs and projects that may have significant effects on the environment. On the other hand, Royal Legislative Decree 2/2011, of September 5, which approves the Consolidated Text of the State Ports and Merchant Marine Act[262], and Law 5/2023, of March 17, on Sustainable Fisheries and Fisheries Research[263] stand out.

Strategic and operational instruments. In the executive, the main competent department is the General Directorate of Coasts and the Sea[264], with the subdirectorates of DPMT, Coastal Protection, and Sea Protection. This department has articulated nine strategies for the protection of the coast[38]. It also deals with post-storm repair works, and the assessment and management of coastal flood risks through Directive 2007/60/EC[265]. On the other hand, all Autonomous communities. have a specific strategic instrument, in addition to different sectoral operational mechanisms (for fishing resources, port activities, protected areas, land uses, cultural activities, tourism, or DPMT)[266]. In 2016, the Strategy for Adaptation to Climate Change for the Spanish Coast[267] was presented, which resulted in actions through the PIMA Adapta COSTA[268]. With this instrument, the Autonomous communities. have been able to assess the vulnerability of their coastal areas[83,269].

Private properties on the border, or in the maritime-terrestrial public domain, are especially vulnerable to the retreat of the coastline. A greater balance is called for with respect to public and private property.

Public-private balance on the coastline. The current retreat of the coastline (as well as the one shown by medium-term forecasts) caused by climate change and coastal erosion is increasing social conflict, as new private properties are affected by the limit of the public domain[222]. Numerous administrative disputes and social movements have been activated calling for the regeneration of[39] beaches to prevent new areas from becoming public domain[274]. In this same context, legislative proposals are framed for the protection of urban areas of cultural, historical or tourist interest that existed before their inclusion in DPMT[275]. There has also been a demand for a greater legal balance with respect to public and private property and that the elimination of private enclaves from the public domain be done effectively and with respect for the rights of individuals). From the point of view of law, there is talk of reconsidering and reconfiguring compensatory concessions in terms of damage, which is the main problem for private landowners in[276,277] coastal areas.

Environmental organizations are calling for deepening basic state competence for environmental protection to preserve unbuilt areas, and create more protected areas.

Environmental protection. The main brake on urbanisation in coastal areas has been placed by nature protection figures[278]. However, 13.5% of the coastal surface still has natural habitats without any protection figure[278]. For this reason, conservation and environmental organizations are asking to deepen basic state competence for environmental protection to preserve unbuilt areas, and to create more protected areas[278]. The benefit of exhaustive and substantive regulations that establish environmental limits to be complied with in land use planning has been noted. For example, sustainable management must consider the carrying capacity of beaches and not grow urbanistically and economically beyond what physical and natural space allows[239]. Despite the risk of a conflict of competence (between environment and land use), on previous occasions, the Constitutional Court (STC 149/1991, FJ 1.B) has supported the regulations established by the State on the basis of its basic environmental competence, understanding that competence in land management cannot override the environmental powers that the Constitution reserves to the State[279,280].

Coastal regulations

The regulation specifies basic coastal legislation, and includes nuances derived from climate change legislation.

Based on the Coastal Law, a regulation is generated that develops legislation. In the 2010s, the regulatory framework did not have a complete methodology for delimiting the boundaries of the maritime terrestrial public domain, which could lead to uncertainties in the technical application and, therefore, in legal rights[281]. In 2024, the Ministry for the Ecological Transition and Demographic Challenge released for public consultation the Draft Royal Decree to modify the General Coastal Regulations of 2014[282]. Its purpose is to make progress in the adaptation of coastal regulations to the current and predicted climate reality, and indicates that there is no regulatory alternative that does not involve a change in the regulation. Specifically, its objectives are: (1) that the regulation modulates and objectives the decision on the granting of concessions and extensions so that the DPMT is protected for public use and enjoyment and to ensure its conservation and protection, (2) adapt the regulation to Law 7/2021, of May 20, on climate change and energy transition, (3) develop the legal definitions of certain DPMT assets, and (4) correct some errors and dysfunctions[282]. A similar reform in 2022 had the approval of[283] environmental organizations, but was declared null and void by the Supreme Court in 2024.

Interaction with the marine and inland waters

The regulation of the marine environment and inland waters is important in coastal management.

With regard to the marine environment, that is, those areas that transcend the DPMT inland, Spain is subject to the European Directive 2008/65/EC, of June 17, 2018, on Marine Strategy, which ensures the good condition of its waters[284]. This directive is transposed into Law 41/2010, of December 29, on the Protection of the Marine Environment[285]. In addition, Spain coordinates its marine management through 5 Maritime Spatial Planning Plans (POEM), approved by Royal Decree 150/2023[286], which ensure sustainable uses of the sea, within the framework of European Directive 2014/89/EU[287]. This Royal Decree addresses the declaration of reserves of strategic sand deposits and their inclusion as DPMT.

With regard to land-sea interaction, particularly on inland waters, the European Water Framework Directive[288] promotes global and inclusive management of all waters, including transition waters (near river mouths) and coastal waters (up to one nautical mile out to sea). This regulation establishes (1) preventing any deterioration of water bodies, (2) achieving good (ecological and chemical) condition, and (3) reducing pollution and eliminating discharges and emissions. Spain regulates transition waters through Water Law[289] and frames them within the DPMT.

Socioecological resilience and relationship with the natural environment

Consideration of the value that the environment brings to people improves social acceptance of coastal interventions. There are successful examples on the Spanish coast.

As a socio-ecological system, any adaptive measure to the pressures of the coastal zone must consider both the natural environment and society, as well as the relationship or interaction between the two[290–292]. This consideration increases the resilience of the area and improves well-being and sustainability in the face of situations of change or disturbances[293]. To ensure that the measures adopted improve the well-being of society and provide the greatest possible support, while using public resources efficiently, it is necessary to take into account all the benefits that society obtains from the ecosystems of coastal areas[10,294,295]. To this end, economic valuation must go beyond the economic contribution to GDP and employment, and take into account all the ecosystem services it provides, and incorporate into the analysis other benefits that contribute to well-being and health, to heritage conservation, to social dynamization, or to personal development linked to the environment[295].

Along these lines, successful experiences have been developed in some parts of the Spanish coast. One of them is the case of the Port of Huelva area. There, a 4-kilometre-long ecological restoration was successfully carried out in which industrial activities were integrated with the natural, social and historical values of the area, with[296] social participation. The preferences of the inhabitants with respect to different native plants were assessed and it was found that although 75% of citizens recognised benefits of coastal wetlands, many were not aware of their ecosystem functions and services[297]. Thus, after the restoration, the number of visitors increased by 27%, and the reasons for visiting it were: walking, cycling, fishing, taking pictures and watching[297] birds. This integration includes environmental education through informational panels[296]. It is one of 116 examples of good practices around the world regarding hybrid city-port integration compiled in a compendium by the "International Association of Cities and Ports"[298].

Regarding beaches or urban spaces, another example is the Barcelona City Council's Coastal Plan, which includes 63 projects along 15kilometres of[299] coastline. Among them, the one focused on the Mar Bella promenade: it has been approved to reorder the space to reduce the pressure of using the dry beach and promote other activities (sports and leisure) in an equipped park and on a naturalised promenade with a terraced edge that improves the city's relationship with the sea, and that is prepared for future scenarios of erosion and rising sea levels[300,301]. Another example is LIFE AdaptCalamillor, a pilot governance project supported by the European Union for adaptation to climate change on the Balearic coast centered on the bay of Cala Millor, an urban beach with more than ten years of environmental monitoring[302]. It includes all the elements of integrated and sustainable management: science, citizen participation, governance and nature-based solutions. The objective is to evaluate adaptation strategies that have the support of society and different stakeholders, with tangible and delimited actions. In the long term, this project aims to serve as inspiration and to be scalable on other urban beaches on the Spanish coast[303]. With the same objective, there is the LIFE Garachico project, in the Canary Islands and in the Azores, to achieve flexible adaptation in coastal areas in the face of extreme events and coastal floods, involving different social and economic actors[304,305].

These and other examples illustrate that the most effective solutions are those hybrid solutions that incorporate engineering knowledge with solutions based on nature, with social participation, within a robust legal framework and with resources that facilitate adaptation to the current and future challenges of the Spanish coast.

Key concepts

- The Spanish coasts are a territory of great ecological and economic value: around 40% of the population lives there, there are important natural areas, and a variety of economic activities are organised there. The Spanish Constitution protects the maritime-terrestrial interface strip, which is in the public domain.

- However, its integrity is threatened by erosion, due to reduced sand input from dams and reservoirs, rising sea levels and destruction after storms. They also face pollution and spills, invasive species and overexploitation of resources. These factors, together with urban pressure and the tourism model, affect coastal ecosystem services.

- The expert community warns that the phase of diagnosing problems is coming to an end and that it is time to propose disruptive plans and actions, assuming some uncertainty. Adapting the coastline remains urgent and represents an opportunity to improve coastal environments.

- The Mediterranean Protocol on Integrated Coastal Zone Management (GIZC, ratified by Spain in 2011) includes guidelines supported by the scientific community and establishes a shift from current sectoral management to an integrated one, but it has not been developed.

- The adaptation of the coastline includes structural or engineering measures, based on nature, or hybrid, that stand out in the face of risks derived from climate change. In parallel, the need for solutions that improve the well-being and connection of people with their environment has also been pointed out.

- Current management is slow and reactive, due to the complexity of the distribution of competencies, land-sea interaction and social aspects, which makes it difficult to implement integrated management.

- Current coastal legislation aims to protect the environment and eliminate private enclaves from the public domain (effectively and with respect for the rights of individuals), but expert voices are calling for more ambition and better integration of sectors such as ports, tourism and land use planning.

- The scientific community specialised in GIZC works to overcome competition barriers, promoting local projects that promote spaces of shared governance between different sectors and administrations.

Bibliography

1. Ministerio de Medio Ambiente. *Perfil Ambiental de España 2006*. https://www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/publicaciones/perfil_ambiental_2006.html (2006).
2. Exceltur. *SOLYTUR 2019. Monitor de competitividad turística de los destinos del 'Sol y Playa' españoles del litoral mediterráneo, Baleares y Canarias*. https://www.exceltur.org/wp-content/uploads/2021/03/Solytur-2019-resumen-ejecutivo-Mar2021.pdf (2021).
3. S.G. Análisis, Coordinación y Estadística & Ministerio de Agricultura, Pesca y Alimentación. *Análisis y Prospectiva – Serie Pesca nº5. DEMOGRAFÍA DE LA POBLACIÓN COSTERA EN 2020*. https://www.mapa.gob.es/es/ministerio/servicios/analisis-y-prospectiva/aypseriepesca5_demografiapoblacioncostera2020_tcm30-617441.pdf (2022).
4. White, M. P. *et al.* Associations between green/blue spaces and mental health across 18 countries. *Scientific Reports* **11**, 8903 (2021) https://doi.org/10.1038/s41598-021-87675-0.
5. Cunsolo, A. & Ellis, N. R. Ecological grief as a mental health response to climate change-related loss. *Nature Climate Change* **8**, 275–281 (2018) https://doi.org/10.1038/s41558-018-0092-2.
6. UNEP. *Marine and coastal ecosystems and human well-being: A synthesis report based on the findings of the Millennium Ecosystem Assessment*. http://www.vliz.be/imisdocs/publications/120064.pdf (2006).
7. Cullen-Unsworth, L. & Unsworth, R. A call for seagrass protection. *Science* **361**, 446–448 (2018) https://doi.org/10.1126/science.aat7318.
8. Blandon, A. & Ermgassen, P. Quantitative estimate of commercial fish enhancement by seagrass habitat in southern Australia. *Estuarine Coastal and Shelf Science* **141**, 1–8 (2014) https://doi.org/10.1016/J.ECSS.2014.01.009.
9. Campagne, C. S., Salles, J., Boissery, P. & Deter, J. The seagrass Posidonia oceanica: Ecosystem services identification and economic evaluation of goods and benefits. *Marine pollution bulletin* **97 1–2**, 391–400 (2015) https://doi.org/10.1016/j.marpolbul.2015.05.061.
10. Guisado-Pintado, E., Navas, F. & Malvárez, G. Ecosystem Services and Their Benefits as Coastal Protection in Highly Urbanised Environments. *Journal of Coastal Research* **75**, 1097–1101 (2016) https://doi.org/10.2112/SI75-220.1.
11. Biodiversity Foundation of the Spanish Ministry of Agriculture, Food and Environment. *Ecosystems and biodiversity for human wellbeing. Synthesis of the key findings*. (2013).
12. EEA. *'EEA indicator: Global and European sea level rise', EEA indicator*. https://www.eea.europa.eu/en/analysis/indicators/global-and-european-sea-level-rise (2024).
13. Morales, J. A. & Pérez-Alberti, A. Introducing the Spanish Coast. *The Spanish Coastal Systems: Dynamic Processes, Sediments and Management* (ed. Morales, J. A.) 1–23 (Springer International Publishing, 2019). ISBN: 978-3-319-93169-2.
14. Cabezas, H., Pawlowski, C., Mayer, A. L. & Hoagland, N. Sustainability: ecological, social, economic, technological, and systems perspectives. *Clean Technologies and Environmental Policy* **5**, 167–180 (2003) https://doi.org/10.1007/S10098-003-0214-Y.
15. Neumann, B., Ott, K. & Kenchington, R. Strong sustainability in coastal areas: a conceptual interpretation of SDG 14. *Sustainability Science* **12**, 1019–1035 (2017) https://doi.org/10.1007/s11625-017-0472-y.
16. Duxbury, J. & Dickinson, S. Principles for sustainable governance of the coastal zone: In the context of coastal disasters. *Ecological Economics* **63**, 319–330 (2007) https://doi.org/10.1016/j.ecolecon.2007.01.016.
17. Jefatura del Estado. *Ley 28/1969, de 26 de abril, sobre costas*. vol. BOE-A-1969-494 6358–6361 (1969).
18. de la Peña Olivas, J. M. Gestión integral e integrada de la costa. *Guía técnica de estudios litorales. Manual de costas* 731–735 (Ibergaceta Publicaciones S.L., 2022). ISBN: 978-84-17289-96-6.
19. Sardá, R. *et al.* Business for ocean sustainability: Early responses of ocean governance in the private sector. *Ambio* **52**, 253–270 (2023) https://doi.org/10.1007/s13280-022-01784-2.
20. Glavovic, B. C. Coastal Innovation Imperative. *Sustainability* **5**, 934–954 (2013) https://doi.org/10.3390/su5030934.
21. Ballinger, R. On the Edge: Coastal Governance and Risk. *Risk Governance: The Articulation of Hazard, Politics and Ecology* (ed. Fra.Paleo, U.) 373–394 (Springer Netherlands, 2015). ISBN: 978-94-017-9328-5.
22. Gallagher, A. The coastal sustainability standard: A management systems approach to ICZM. *Ocean & Coastal Management* **53**, 336–349 (2010) https://doi.org/10.1016/j.ocecoaman.2010.04.017.
23. García García, M. Hacia la metamorfosis sintética de la costa diseñando paisajes resilientes. (E.T.S. Arquitectura (UPM), 2017).
24. European Environment Agency. *Marine messages II: Navigating the course towards clean, healthy and productive seas through implementation of an ecosystem-based approach*. https://www.eea.europa.eu/publications/marine-messages-2/ (2019).
25. Richardson, C. M. *et al.* The impacts of climate change on coastal groundwater. *Nature Reviews Earth & Environment* **5**, 100–119 (2024) https://doi.org/10.1038/s43017-023-00500-2.
26. Villasante, S. *et al. Building Coastal Resilience in Europe*. Position Paper 27 https://zenodo.org/record/8224055 (2023) https://doi.org/10.5281/ZENODO.8224055.
27. European Environment Agency. *European climate risk assessment (EEA Report 01/2024)*. https://www.eea.europa.eu/publications/european-climate-risk-assessment (2024).
28. European Environment Agency. *State of nature in the EU: Results from reporting under the nature directives 2013 - 2018*. Report No 10/2020 https://www.eea.europa.eu/publications/state-of-nature-in-the-eu-2020 (2020).
29. Ecologistas en Acción. *Informe Banderas Negras 2024*. https://www.ecologistasenaccion.org/318735/informe-banderas-negras-2024/ (2024).
30. Río, L. D., Gracia, F. & Benavente, J. Shoreline change patterns in sandy coasts. A case study in SW Spain. *Geomorphology* **196**, 252–266 (2013) https://doi.org/10.1016/J.GEOMORPH.2012.07.027.
31. Rodriguez-Galiano, V., Guisado-Pintado, E., Prieto-Campos, A. & Ojeda-Zujar, J. A machine-learning hybrid-classification method for stratification of multidecadal beach dynamics. *Geocarto International* **37**, 16534–16558 (2022) https://doi.org/10.1080/10106049.2022.2110616.
32. Garcia-Lozano, C., Pintó, J. & Daunis-i-Estadella, P. Changes in coastal dune systems on the Catalan shoreline (Spain, NW Mediterranean Sea). Comparing dune landscapes between 1890 and 1960 with their current status. *Estuarine, Coastal and Shelf Science* **208**, 235–247 (2018) https://doi.org/10.1016/j.ecss.2018.05.004.
33. Muñoz-Pérez, J. J., Román-Blanco, B. L. de S., Gutiérrez-Mas, J., Moreno, L. & Cuena, G. Cost of beach maintenance in the Gulf of Cadiz (SW Spain). *Coastal Engineering* **42**, 143–153 (2001) https://doi.org/10.1016/S0378-3839(00)00054-5.
34. Arabadzhyan, A., Figini, P., García, C., González, M. M., Lam-González, Y. E. & León, C. J. Climate change, coastal tourism, and impact chains – a literature review. *Current Issues in Tourism* **24**, 2233–2268 (2021) https://doi.org/10.1080/13683500.2020.1825351.
35. Enríquez, A. R. & Bestard, A. B. Measuring the economic impact of climate-induced environmental changes on sun-and-beach tourism. *Climatic Change* **160**, 203–217 (2020) https://doi.org/10.1007/s10584-020-02682-w.
36. de Santiago, I. *et al.* Impact of climate change on beach erosion in the Basque Coast (NE Spain). *Coastal Engineering* **167**, 103916 (2021) https://doi.org/10.1016/j.coastaleng.2021.103916.
37. Fernández, E., Álvarez-Salgado, X. A., Beiras, R., Ovejero, A. & Méndez, G. Coexistence of urban uses and shellfish production in an upwelling-driven, highly productive marine environment: The case of the Ría de Vigo (Galicia, Spain). *Regional Studies in Marine Science* **8**, 362–370 (2016) https://doi.org/10.1016/j.rsma.2016.04.002.
38. Estrategias para la protección de la costa. *Ministerio para la Transición Ecológica y el Reto Demográfico* https://www.miteco.gob.es/es/costas/temas/proteccion-costa/estrategias-proteccion-costa.html [03/07/2024].
39. Congreso por la regeneración de las costas españolas organizado e impulsado por la Concejalía de Playas del Ayuntamiento de Oropesa del Mar. *Cada grano de arena cuenta* https://www.cadagranodearenacuenta.es/ [03/07/2024].
40. el7set. III Congreso por la Regeneración de las Costas Españolas: Un compromiso unánime con la conservación del litoral. *El 7 Set noticias de la Plana y el Maestrat* http://el7set.es//art/46538/iii-congreso-por-la-regeneracion-de-las-costas-espanolas-un-compromiso-unanime-con-la-conservacion-del-litoral [16/10/2024].
41. Moreno, L. J. & Muñoz-Perez, J. J. Beach Nourishment: A 21st Century Review. *Journal of Marine Science and Engineering* **9**, 499 (2021) https://doi.org/10.3390/jmse9050499.
42. Stive, M. J. F. *et al.* A New Alternative to Saving Our Beaches from Sea-Level Rise: The Sand Engine. *Journal of Coastal Research* **29**, 1001–1008 (2013) https://doi.org/10.2112/JCOASTRES-D-13-00070.1.
43. BOE-B-2022-23946 Anuncio de licitación de: Dirección General de la Costa y el Mar. Objeto: Proyecto de regeneración de las playas del Saler y Garrofera (Valencia), en el Marco del Plan de Recuperación, Transformación y Resiliencia (PRTR). Expediente: P02.C05.I04.P01.94_46-0351. https://www.boe.es/diario_boe/txt.php?id=BOE-B-2022-23946 [19/09/2024].
44. Greenpeace España. *Crisis a toda costa*. https://es.greenpeace.org/es/wp-content/uploads/sites/3/2024/07/crisis-a-toda-costa-2024.pdf (2024).
45. Cooper, K. M., Curtis, M., Wan Hussin, W. M. R., Barrio Froján, C. R. S., Defew, E. C., Nye, V. & Paterson, D. M. Implications of dredging induced changes in sediment particle size composition for the structure and function of marine benthic macrofaunal communities. *Marine Pollution Bulletin* **62**, 2087–2094 (2011) https://doi.org/10.1016/j.marpolbul.2011.07.021.
46. Reig, L., Pitarch, Á. M., Soriano, L., Borrachero, M. V., Monzó, J. M., Payá, J. & Tashima, M. M. Ceramic Waste: Reuse as a Recycled Aggregate. *Building Engineering Facing the Challenges of the 21st Century: Holistic Study from the Perspectives of Materials, Construction, Energy and Sustainability* (eds. Bienvenido-Huertas, D. & Durán-Álvarez, J.) 533–551 (Springer Nature, 2023). ISBN: 978-981-9927-14-2.
47. Productos - Tratamiento de residuos Castellón | Hope & Effort. https://www.hopeffort.es/productos/ [11/07/2024].
48. Grases, A., Gracia, V., García-León, M., Lin-Ye, J. & Sierra, J. P. Coastal Flooding and Erosion under a Changing Climate: Implications at a Low-Lying Coast (Ebro Delta). *Water* **12**, 346 (2020) https://doi.org/10.3390/w12020346.
49. Molina, R., Anfuso, G., Manno, G. & Gracia Prieto, F. J. The Mediterranean Coast of Andalusia (Spain): Medium-Term Evolution and Impacts of Coastal Structures. *Sustainability* **11**, 3539 (2019) https://doi.org/10.3390/su11133539.
50. Losada, I., Izaguirre, C. & Diaz, P. *Cambio climático en la costa española. Oficina Española de Cambio Climático. Ministerio de Agricultura, Alimentación y Medio Ambiente*. 133

https://www.chj.es/Descargas/ProyectosOPH/Consulta%20publica/PHC-2021-2027/PHJ/ReferenBibliograficas/Losada,I.J.etal,2014_CambioClimaticoCostaEspa%C3%B1ola.pdf (2014).
51. Floerl, O. *et al.* A global model to forecast coastal hardening and mitigate associated socioecological risks. *Nature Sustainability* **4**, 1060–1067 (2021) https://doi.org/10.1038/s41893-021-00780-w.
52. Ferradás Carrasco, S. El consumo del espacio litoral en las ciudades turísticas. *Espacio y Tiempo: Revista de Ciencias Humanas* 251–270 (2009) https://doi.org/ISSN:1885-0138.
53. Borchert, S. M., Osland, M. J., Enwright, N. & Griffith, K. Coastal wetland adaptation to sea level rise: Quantifying potential for landward migration and coastal squeeze. *Journal of Applied Ecology* (2018) https://doi.org/10.1111/1365-2664.13169.
54. Enwright, N., Griffith, K. & Osland, M. J. Barriers to and opportunities for landward migration of coastal wetlands with sea-level rise. *Frontiers in Ecology and the Environment* **14**, 307–316 (2016) https://doi.org/10.1002/FEE.1282.
55. de Andrés, M., Barragán, J. M. & García Sanabria, J. Ecosystem services and urban development in coastal Social-Ecological Systems: The Bay of Cádiz case study. *Ocean & Coastal Management* **154**, 155–167 (2018) https://doi.org/10.1016/j.ocecoaman.2018.01.011.
56. Davenport, J. & Davenport, J. L. The impact of tourism and personal leisure transport on coastal environments: A review. *Estuarine Coastal and Shelf Science* **67**, 280–292 (2006) https://doi.org/10.1016/J.ECSS.2005.11.026.
57. Hattam, C. *et al.* Marine ecosystem services: Linking indicators to their classification. *Ecological Indicators* **49**, 61–75 (2015) https://doi.org/10.1016/j.ecolind.2014.09.026.
58. Fraile-Jurado, P., Álvarez-Francoso, J. I., Guisado-Pintado, E., Sánchez-Carnero, N., Ojeda-Zújar, J. & Leatherman, S. P. Mapping inundation probability due to increasing sea level rise along El Puerto de Santa María (SW Spain). *Natural Hazards* **87**, 581–598 (2017) https://doi.org/10.1007/s11069-017-2782-x.
59. Fraile Jurado, P., Guisado Pintado, E., Álvarez Francoso, J. I., Díaz Cuevas, M. del P. & Ojeda Zújar, J. Wave energy patterns under different sea level rise (SLR) probabilities in the Andalusian Atlantic coast. (2020) https://doi.org/10.2112/SI95-212.1.
60. National Oceanic and Atmospheric Administration. *A NOAA Capability for: Coastal Flooding and Inundation Information and Services at Climate Timescales to Reduce Risk and Improve Resilience*. https://cpo.noaa.gov/wp-content/uploads/2023/08/NOAA-Coastal-Inundation-at-Climate-Timescales-Whitepaper.pdf (2022).
61. IPCC. *Climate Change 2013: The Physical Science Basis. Contribution of WG1 to the IPCC AR5. Sea Level Change*. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter13_FINAL.pdf (2013).
62. IPCC. *Climate Change 2013: The Physical Science Basis. Contribution of WG1 to the IPCC AR5. Summary for Policymakers*. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_SPM_FINAL.pdf (2013).
63. How are CO concentrations related to warming? *Fakta o klimatu* https://factsonclimate.org/infographics/concentration-warming-relationship [01/04/2024].
64. Le Cozannet, G., Durand, G. & Nicholls, R. *When will a 2-metre rise in seae level occur, and how might we adapt? (PROTECT/COCLICO/SCORE)*. https://cloud.univ-grenoble-alpes.fr/s/J4WRBw4cbzd3biK (2023).
65. Spain Flood Map: Elevation Map, Sea Level Rise Map. https://www.floodmap.net/?ct=ES [28/05/2024].
66. Williams, R. G., Roussenov, V., Frölicher, T. L. & Goodwin, P. Drivers of Continued Surface Warming After Cessation of Carbon Emissions. *Geophysical Research Letters* **44**, 10,633-10,642 (2017) https://doi.org/10.1002/2017GL075080.
67. Knutti, R. & Rogelj, J. The legacy of our CO2 emissions: a clash of scientific facts, politics and ethics. *Climatic Change* **133**, 361–373 (2015) https://doi.org/10.1007/s10584-015-1340-3.
68. Zickfeld, K., Azevedo, D., Mathesius, S. & Matthews, H. D. Asymmetry in the climate–carbon cycle response to positive and negative CO2 emissions. *Nature Climate Change* **11**, 613–617 (2021) https://doi.org/10.1038/s41558-021-01061-2.
69. Hansen, J. E. *et al.* Global warming in the pipeline. *Oxford Open Climate Change* **3**, kgad008 (2023) https://doi.org/10.1093/oxfclm/kgad008.
70. OECD. *Climate Tipping Points: Insights for Effective Policy Action*. (Organisation for Economic Co-operation and Development, 2022).
71. Moon, T., Ahlstrøm, A., Goelzer, H., Lipscomb, W. & Nowicki, S. Rising Oceans Guaranteed: Arctic Land Ice Loss and Sea Level Rise. *Current Climate Change Reports* **4**, 211–222 (2018) https://doi.org/10.1007/s40641-018-0107-0.
72. Bakker, A. M. R., Wong, T. E., Ruckert, K. L. & Keller, K. Sea-level projections representing the deeply uncertain contribution of the West Antarctic ice sheet. *Scientific Reports* **7**, 3880 (2017) https://doi.org/10.1038/s41598-017-04134-5.
73. Kopp, R. E. *et al.* Evolving Understanding of Antarctic Ice-Sheet Physics and Ambiguity in Probabilistic Sea-Level Projections. *Earth's Future* **5**, 1217–1233 (2017) https://doi.org/10.1002/2017EF000663.
74. DeConto, R. M. *et al.* The Paris Climate Agreement and future sea-level rise from Antarctica. *Nature* **593**, 83–89 (2021) https://doi.org/10.1038/s41586-021-03427-0.
75. Fox-Kemper, B. *et al.* Chapter 9: Ocean, Cryosphere and Sea Level Change. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge University Press, 2021).
76. Schmidt, G. Climate models can't explain 2023's huge heat anomaly — we could be in uncharted territory. *Nature* **627**, 467–467 (2024) https://doi.org/10.1038/d41586-024-00816-z.
77. Biló, T. C., Perez, R. C., Dong, S., Johns, W. & Kanzow, T. Weakening of the Atlantic Meridional Overturning Circulation abyssal limb in the North Atlantic. *Nature Geoscience* **17**, 419–425 (2024) https://doi.org/10.1038/s41561-024-01422-4.
78. Mengel, M., Nauels, A., Rogelj, J. & Schleussner, C.-F. Committed sea-level rise under the Paris Agreement and the legacy of delayed mitigation action. *Nature Communications* **9**, 601 (2018) https://doi.org/10.1038/s41467-018-02985-8.
79. García-Ayllón, S. & Radke, J. Geostatistical Analysis of the Spatial Correlation between Territorial Anthropization and Flooding Vulnerability: Application to the DANA Phenomenon in a Mediterranean Watershed. *Applied Sciences* (2021) https://doi.org/10.3390/APP11020809.
80. Eguibar, M., Porta-García, R., Torrijo, F. & Garzón-Roca, J. Flood Hazards in Flat Coastal Areas of the Eastern Iberian Peninsula: A Case Study in Oliva (Valencia, Spain). *Water* (2021) https://doi.org/10.3390/w13212975.
81. Manero Lecea, G. Análisis de los temporales marinos entre 2013-2014 y de sus impactos en las costas de Cantabria. (2015).
82. Amores, Á., Marcos, M., Carrió, D. & GómezPujol, L. Coastal impacts of Storm Gloria (January 2020) over the north-western Mediterranean. *Natural Hazards and Earth System Sciences* (2020) https://doi.org/10.5194/nhess-2020-75.
83. Departament d'Acció Climàtica, Alimentació i Agenda Rural, Generalitat de Catalunya & Servei Meteorològic de Catalunya. *Estudio de la evolución de los temporales de mar históricos en la costa catalana a partir de las observaciones y las simulaciones marítimas (1990-2020)*. https://canviclimatic.gencat.cat/web/.content/02_OFICINA/publicacions/publicacions_de_canvi_climatic/Estudis_i_docs_adaptacio/PIMA_Adapta_Costas/PIMA-Informe-temporals-martims-jul2021_v2_correccions_OCCC.pdf (2021).
84. Cooley, S. R. & Schoeman, D. S. *Chapter 3: Oceans and Coastal Ecosystems and their Services*. https://www.ipcc.ch/report/ar6/wg2/chapter/chapter-3/ .
85. González-Alemán, J. J., Pascale, S., Gutierrez-Fernandez, J., Murakami, H., Gaertner, M. A. & Vecchi, G. A. Potential Increase in Hazard From Mediterranean Hurricane Activity With Global Warming. *Geophysical Research Letters* **46**, 1754–1764 (2019) https://doi.org/10.1029/2018GL081253.
86. Sotillo, M. G., Cerralbo, P., Lorente, P., Grifoll, M., Espino, M., Sanchez-Arcilla, A. & Álvarez-Fanjul, E. Coastal ocean forecasting in Spanish ports: the SAMOA operational service. *Journal of Operational Oceanography* **13**, 37–54 (2020) https://doi.org/10.1080/1755876X.2019.1606765.
87. Centro Nacional de Información Geográfica (Ministerio de Transportes, Movilidad y Agenda Urbana. *Plan Estatal de Protección Civil ante el riesgo de maremotos. Edición comentada*. (2021).
88. Benson, N., Agboola, O. D., Fred-Ahmadu, O. H., De-la-Torre, G., Oluwalana, A. & Williams, A. B. Micro(nano) plastics Prevalence, Food Web Interactions, and Toxicity Assessment in Aquatic Organisms: A Review. **9**, (2022) https://doi.org/10.3389/fmars.2022.851281.
89. Bergami, E., Bocci, E., Vannuccini, M., Monopoli, M., Salvati, A., Dawson, K. & Corsi, I. Nano-sized polystyrene affects feeding, behavior and physiology of brine shrimp Artemia franciscana larvae. *Ecotoxicology and environmental safety* **123**, 18–25 (2016) https://doi.org/10.1016/j.ecoenv.2015.09.021.
90. Lee, J., Jeong, S. & Chae, K.-J. Discharge of microplastics fibres from wet wipes in aquatic and solid environments under different release conditions. *Science of The Total Environment* **784**, 147144 (2021) https://doi.org/10.1016/j.scitotenv.2021.147144.
91. Ó Briain, O., Marques Mendes, A. R., McCarron, S., Healy, M. G. & Morrison, L. The role of wet wipes and sanitary towels as a source of white microplastic fibres in the marine environment. *Water Research* **182**, 116021 (2020) https://doi.org/10.1016/j.watres.2020.116021.
92. Malone, T. C. & Newton, A. The Globalization of Cultural Eutrophication in the Coastal Ocean: Causes and Consequences. *Frontiers in Marine Science* **7**, (2020) https://doi.org/10.3389/fmars.2020.00670.
93. Breitburg, D. *et al.* Declining oxygen in the global ocean and coastal waters. *Science* **359**, eaam7240 (2018) https://doi.org/10.1126/science.aam7240.
94. Kemp, W. M., Testa, J. M., Conley, D. J., Gilbert, D. & Hagy, J. D. Temporal responses of coastal hypoxia to nutrient loading and physical controls. *Biogeosciences* **6**, 2985–3008 (2009) https://doi.org/10.5194/bg-6-2985-2009.
95. *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy*. (2014).
96. *Council Directive of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/EEC)*. (2008).
97. *Council Directive of 21 May 1991 concerning urban waste water treatment (91/271/EEC)*. (2014).
98. *Directive 2006/7/EC of the European Parliament and of the Council of 15 February 2006 concerning the management of bathing water quality and repealing Directive 76/160/EEC*. (2014).
99. *Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora*. (2013).
100. Piroddi, C. *et al.* Effects of Nutrient Management Scenarios on Marine Food Webs: A Pan-European Assessment in Support of the Marine Strategy Framework Directive. *Frontiers in Marine Science* **8**, (2021) https://doi.org/10.3389/fmars.2021.596797.

101. Ecologistas en Acción. *La contaminación por nitratos y su impacto en el medio ambiente y el agua de consumo humano*. https://www.ecologistasenaccion.org/311484/informe-la-contaminacion-por-nitratos-y-su-impacto-en-el-medio-ambiente-y-el-agua-de-consumo-humano/ (2024).
102. European Maritime Transport Environmental Report 2021 — European Environment Agency. https://www.eea.europa.eu/publications/maritime-transport [28/05/2024].
103. Duarte, C. M. *et al.* The soundscape of the Anthropocene ocean. *Science* **371**, eaba4658 (2021) https://doi.org/10.1126/science.aba4658.
104. Thomsen, F. *et al. Addressing underwater noise in Europe: Current state of knowledge and future priorities*. https://zenodo.org/record/5534224 (2021) https://doi.org/10.5281/ZENODO.5534224.
105. Byrnes, T. A. & Dunn, R. J. K. Boating- and Shipping-Related Environmental Impacts and Example Management Measures: A Review. *Journal of Marine Science and Engineering* **8**, 908 (2020) https://doi.org/10.3390/jmse8110908.
106. Megías, C. & Ecologistas en Acción. *Emisarios submarinos: brev guía*. https://www.ecologistasenaccion.org/182194 (2021).
107. Landrigan, P. *et al.* Human Health and Ocean Pollution. *Annals of Global Health* **86**, (2020) https://doi.org/10.5334/aogh.2831.
108. Palomar, P. & Losada, I. Desalination in Spain: Recent developments and recommendations. *Desalination* **255**, 97–106 (2010) https://doi.org/10.1016/J.DESAL.2010.01.008.
109. Gacia, E., Invers, O., Manzanera, M., Ballesteros, E. & Romero, J. Impact of the brine from a desalination plant on a shallow seagrass (Posidonia oceanica) meadow. *Estuarine Coastal and Shelf Science* **72**, 579–590 (2007) https://doi.org/10.1016/J.ECSS.2006.11.021.
110. Pascual, M., Borja, A., Franco, J., Burdon, D., Atkins, J. P. & Elliott, M. What are the costs and benefits of biodiversity recovery in a highly polluted estuary? *Water Research* **46**, 205–217 (2012) https://doi.org/10.1016/j.watres.2011.10.053.
111. Borja, Á., Muxika, I. & Franco, J. Long-term recovery of soft-bottom benthos following urban and industrial sewage treatment in the Nervión estuary (southern Bay of Biscay). *Marine Ecology Progress Series* **313**, 43–55 (2006) https://doi.org/10.3354/meps313043.
112. Oil Tanker Spill Statistics 2023 - ITOPF. https://www.itopf.org/knowledge-resources/data-statistics/statistics/ [28/05/2024].
113. Pilar, S. A. El vertido sobre la Albufera pone de relieve la fragilidad de este humedal, uno de los más importantes de España. *RTVE.es* https://www.rtve.es/noticias/20240717/vertido-sobre-albufera-vuelve-a-poner-relieve-fragilidad-este-humedal-uno-mas-importantes-espana/16189006.shtml [25/09/2024].
114. Ministerio de Agricultura, Alimentación y Medio Ambiente. *Orden AAA/702/2014, de 28 de abril, por la que se aprueba el Plan Estatal de Protección de la Ribera del Mar contra la Contaminación*. vol. BOE-A-2014-4651 34450–34464 (2014).
115. Crowder, L. B., Hazen, E. L., Avissar, N., Bjorkland, R., Latanich, C. & Ogburn, M. B. The Impacts of Fisheries on Marine Ecosystems and the Transition to Ecosystem-Based Management. *Annual Review of Ecology, Evolution, and Systematics* **39**, 259–278 (2008) https://doi.org/10.1146/annurev.ecolsys.39.110707.173406.
116. Möllmann, C. *et al.* Tipping point realized in cod fishery. *Scientific Reports* **11**, 14259 (2021) https://doi.org/10.1038/s41598-021-93843-z.
117. Favoretto, F., López-Sagástegui, C., Sala, E. & Aburto-Oropeza, O. The largest fully protected marine area in North America does not harm industrial fishing. *Science Advances* **9**, eadg0709 (2023) https://doi.org/10.1126/sciadv.adg0709.
118. Sala, E. & Giakoumi, S. No-take marine reserves are the most effective protected areas in the ocean. *ICES Journal of Marine Science* **75**, 1166–1168 (2018) https://doi.org/10.1093/icesjms/fsx059.
119. Biodiversity strategy for 2030 - European Commission. https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en [15/07/2024].
120. Dobson, J. Y., Flores-García, A., Fonfría, E. S., García, D., Sumaila, R. & Bordehore, C. Understanding the Fisheries Crisis: Unraveling the Interplay Between Subsidies, Marine Reserves, and Fishing Effort. (2023).
121. Oceana. *50 refugios marinos de España. Propuesta de áreas marinas de protección estricta*. https://europe.oceana.org/wp-content/uploads/sites/26/2023/09/OCEANA-50-REFUGIOS-MARINOS-DE-ESPANA-OCTUBRE-2023.pdf (2023).
122. Seas At Risk, Marine Conservation Society and Oceana. *A quantification of bottom towed fishing activity in marine Natura 2000 sites*. https://europe.oceana.org/wp-content/uploads/sites/26/2024/04/FINAL-BTG-natura-2000.pdf (2024).
123. ANSE *et al. Mediterráneo 30x30. Acuerdo marino entre organizaciones ambientales para la protección de un 30% del Mediterráneo español en 2030*. https://europe.oceana.org/wp-content/uploads/sites/26/2024/02/Acuerdo-Azul_def_ONLINE.pdf (2024).
124. La pesca de arrastre en áreas marinas protegidas españolas acumula 460.000 horas en nueve años. *Oceana Europe* https://europe.oceana.org/es/press-releases/la-pesca-de-arrastre-en-areas-marinas-protegidas-espanolas-acumula-460-000-horas-en-nueve-anos/ [28/06/2024].
125. ICES. *EU request on spatial trade-off analysis between reducing the extent of mobile bottom-contacting gear (MBCG) disturbance to seabed habitats and potential costs to fisheries*. https://ices-library.figshare.com/articles/report/EU_request_on_spatial_trade-off_analysis_between_reducing_the_extent_of_mobile_bottom-contacting_gear_MBCG_disturbance_to_seabed_habitats_and_potential_costs_to_fisheries/25601121/1 (2024) https://doi.org/10.17895/ices.advice.25601121.v1.
126. *COMUNICACIÓN DE LA COMISIÓN AL PARLAMENTO EUROPEO, AL CONSEJO, AL COMITÉ ECONÓMICO Y SOCIAL EUROPEO Y AL COMITÉ DE LAS REGIONES Plan de acción de la UE: proteger y restaurar los ecosistemas marinos en pro de una pesca sostenible y resiliente*. (2023).
127. Hassoun, A. E. R. *et al.* Ocean acidification research in the Mediterranean Sea: Status, trends and next steps. *Frontiers in Marine Science* **9**, (2022) https://doi.org/10.3389/fmars.2022.892670.
128. García-Gómez, J. C. *et al.* From exotic to invasive in record time: The extreme impact of *Rugulopteryx okamurae* (Dictyotales, Ochrophyta) in the strait of Gibraltar. *Science of The Total Environment* **704**, 135408 (2020) https://doi.org/10.1016/j.scitotenv.2019.135408.
129. Ministerio para la Transición Ecológica y el Reto Demográfico. *Memoria Técnica Justificativa. Rugulopteryx okamurae. Catálogo Español de Especies Exóticas Invasoras*. https://www.miteco.gob.es/content/dam/miteco/es/biodiversidad/temas/conservacion-de-especies/mtjrugulopteryxokamurae_tcm30-523165.pdf (2020).
130. Galil, B. S., Marchini, A., Occhipinti-Ambrogi, A., Minchin, D., Narščius, A., Ojaveer, H. & Olenin, S. International arrivals: widespread bioinvasions in European Seas. *Ethology Ecology & Evolution* **26**, 152–171 (2014) https://doi.org/10.1080/03949370.2014.897651.
131. King, N. G. *et al.* Climate change accelerates range expansion of the invasive non-native species, the Pacific oyster, Crassostrea gigas. *ICES Journal of Marine Science* **78**, 70–81 (2021) https://doi.org/10.1093/icesjms/fsaa189.
132. Glasby, T. M., Connell, S. D., Holloway, M. G. & Hewitt, C. L. Nonindigenous biota on artificial structures: could habitat creation facilitate biological invasions? *Marine Biology* **151**, 887–895 (2007) https://doi.org/10.1007/s00227-006-0552-5.
133. Airoldi, L., Turon, X., Perkol-Finkel, S. & Rius, M. Corridors for aliens but not for natives: effects of marine urban sprawl at a regional scale. *Diversity and Distributions* **21**, 755–768 (2015) https://doi.org/10.1111/ddi.12301.
134. Dafforn, K. A., Glasby, T. M. & Johnston, E. L. Comparing the Invasibility of Experimental "Reefs" with Field Observations of Natural Reefs and Artificial Structures. *PLOS ONE* **7**, e38124 (2012) https://doi.org/10.1371/journal.pone.0038124.
135. *The First Global Integrated Marine Assessment: World Ocean Assessment I*. (Cambridge University Press, 2017). ISBN: 978-1-316-51001-8.
136. MInisterio de Transición Ecológica y el Reto Demográfico. *Estrategia de control del alga Rugulopteryx okamurae en España*. https://www.miteco.gob.es/content/dam/miteco/es/biodiversidad/publicaciones/estrategias/estrategia_rokamurae_cs_28072022_tcm30-543560.pdf (2022).
137. Barcellos, L., Pham, C., Menezes, G., Bettencourt, R., Rocha, N., Carvalho, M. & Felgueiras, H. A Concise Review on the Potential Applications of Rugulopteryx okamurae Macroalgae. *Marine Drugs* **21**, (2023) https://doi.org/10.3390/md21010040.
138. Ministerio de Agricultura, Alimentación y Medio Ambiente. *Real Decreto 630/2013, de 2 de agosto, por el que se regula el Catálogo español de especies exóticas invasoras*. vol. BOE-A-2013-8565 56764–56786 (2013).
139. Png-González, L., Cefali, M. E., Comas-González, R., Ballesteros, E. & Carbonell, A. *Especies exóticas e invasoras en el mar Balear*. https://digital.csic.es/handle/10261/317694 (2021).
140. Garrabou, J. & Broglio, E. Observadores del Mar, diez años de ciencia ciudadana marina. (2022).
141. Martínez-Laiz, G., Bazairi, H., Espinosa, F., Peñalver-Duque, P., León-Muez, D., García-Gutiérrez, M. L. & Terrón-Sigler, A. Public engagement and its challenging role in conservation and monitoring. *Coastal Habitat Conservation: New Perspectives and Sustainable Development of Biodiversity in the Anthropocene* 193–224 (2022).
142. Reyes, E. *et al.* Coastal high-frequency radars in the Mediterranean – Part 2: Applications in support of science priorities and societal needs. *Ocean Science* **18**, 797–837 (2022) https://doi.org/10.5194/os-18-797-2022.
143. Abalia, A., de Santiago, I., Liria, P., Garnier, R., Epelde, I., Nieto, A. & Morichon, D. Analysis of the coastal flooding exposure of embayed beaches at a regional scale using a video monitoring network: Basque Coast (Spain). *Ocean & Coastal Management* **254**, 107193 (2024) https://doi.org/10.1016/j.ocecoaman.2024.107193.
144. Nieto, M. A. *et al.* An open source, low cost video-based coastal monitoring system. *Earth Surface Processes and Landforms* **35**, 1712–1719 (2010) https://doi.org/10.1002/esp.2025.
145. Pahlevan, N. *et al.* Seamless retrievals of chlorophyll-*a* from Sentinel-2 (MSI) and Sentinel-3 (OLCI) in inland and coastal waters: A machine-learning approach. *Remote Sensing of Environment* **240**, 111604 (2020) https://doi.org/10.1016/j.rse.2019.111604.
146. Sentinel-3. https://sentiwiki.copernicus.eu/web/sentinel-3 [11/07/2024].
147. D'Urban Jackson, T., Williams, G. J., Walker-Springett, G. & Davies, A. J. Three-dimensional digital mapping of ecosystems: a new era in spatial ecology. *Proceedings of the Royal Society B: Biological Sciences* **287**, 20192383 (2020) https://doi.org/10.1098/rspb.2019.2383.
148. Harley, M. D., Kinsela, M. A., Sánchez-García, E. & Vos, K. Shoreline change mapping using crowd-sourced smartphone images. *Coastal Engineering* **150**, 175–189 (2019) https://doi.org/10.1016/j.coastaleng.2019.04.003.
149. Harley, M. D. & Kinsela, M. A. CoastSnap: A global citizen science program to monitor changing coastlines. *Continental Shelf Research* **245**, 104796 (2022) https://doi.org/10.1016/j.csr.2022.104796.

150. González-Villanueva, R. *et al.* SCShores: a comprehensive shoreline dataset of Spanish sandy beaches from a citizen-science monitoring programme. *Earth System Science Data* **15**, 4613–4629 (2023) https://doi.org/10.5194/essd-15-4613-2023.
151. López Trigal, L. *Diccionario de geografía aplicada y profesional: terminología de análisis, planificación y gestión del territorio*. (2015). ISBN: 978-84-9773-722-7.
152. Commission of the european communities. *COMMUNICATION FROM THE COMMISSION TO THE COUNCIL AND THE EUROPEAN PARLIAMENT ON INTEGRATED COASTAL ZONE MANAGEMENT: A STRATEGY FOR EUROPE. COM(2000) 547 final.* https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2000:0547:FIN:EN:PDF (2000).
153. Jefatura del Estado. *Instrumento de Ratificación del Protocolo relativo a la gestión integrada de las zonas costeras del Mediterráneo, hecho en Madrid el 21 de enero de 2008*. vol. BOE-A-2011-5294 30849–30863 (2011).
154. ICZM Protocol | UNEPMAP. https://www.unep.org/unepmap/who-we-are/contracting-parties/iczm-protocol [04/09/2024].
155. Sardá, R. Hacia una Gestión Integrada de la Zona Costera basada en la Gestión por Ecosistema. *Capacitat de càrrega i gestió adaptativa per a la preservació dels ecosistemes marins i costaners* vol. 7 119 (Documenta Universitaria, 2020). ISBN: 978-84-9984-555-5.
156. Barragán, J. M. & García Sanabria, J. *Estrategia de gestión integrada de zonas costeras en el mar menor y su entorno*. https://canalmarmenor.carm.es/wp-content/uploads/Estrategia-de-Gestion-Integrada-de-zonas-costeras-en-el-Mar-Menor-y-su-entorno.pdf (2021).
157. Barragán Muñoz, J. M., García Sanabria, J. & de Andrés García, M. ICZM Strategy for the Socioecological System of the Mar Menor (Spain): Methodological Aspects and Public Participation. *Socio-ecological Studies in Natural Protected Areas: Linking Community Development and Conservation in Mexico* (ed. Ortega-Rubio, A.) 243–272 (Springer International Publishing, 2020). ISBN: 978-3-030-47264-1.
158. Jiang, P. *et al.* Digital Twin Earth -- Coasts: Developing a fast and physics-informed surrogate model for coastal floods via neural operators. (2021) http://arxiv.org/abs/2110.07100.
159. Haasnoot, M., Brown, S., Scussolini, P., Jimenez, J. A., Vafeidis, A. T. & Nicholls, R. J. Generic adaptation pathways for coastal archetypes under uncertain sea-level rise. *Environmental Research Communications* **1**, 071006 (2019) https://doi.org/10.1088/2515-7620/ab1871.
160. de Andrés, M., Barragán, J. M. & García Sanabria, J. Relationships between coastal urbanization and ecosystems in Spain. *Cities* **68**, 8–17 (2017) https://doi.org/10.1016/j.cities.2017.05.004.
161. Fu, X., Gomaa, M., Deng, Y. & Peng, Z. Adaptation planning for sea level rise: a study of US coastal cities. *Journal of Environmental Planning and Management* **60**, 249–265 (2017) https://doi.org/10.1080/09640568.2016.1151771.
162. Albers, M. & Deppisch, S. Resilience in the Light of Climate Change: Useful Approach or Empty Phrase for Spatial Planning? *European Planning Studies* **21**, 1598–1610 (2013) https://doi.org/10.1080/09654313.2012.722961.
163. Spirandelli, D. J., Anderson, T., Porro, R. & Fletcher, C. Improving Adaptation Planning for Future Sea-Level Rise. *Journal of Planning Education and Research* **36**, 290–303 (2016) https://doi.org/10.1177/0739456X16657160.
164. Käyhkö, N., Khamis, Z. A., Eilola, S., Virtanen, E., Muhammad, M. J., Viitasalo, M. & Fagerholm, N. The role of place-based local knowledge in supporting integrated coastal and marine spatial planning in Zanzibar, Tanzania. *Ocean & Coastal Management* **177**, 64–75 (2019) https://doi.org/10.1016/j.ocecoaman.2019.04.016.
165. Gee, K. & Siedschlag, D. A place-based perspective on marine and coastal space. *Europa XXI* **36**, 61–75 (2019) https://doi.org/10.7163/Eu21.2019.36.6.
166. Newell, R. & Canessa, R. Picturing a place by the sea: Geovisualizations as place-based tools for collaborative coastal management. *Ocean & Coastal Management* **141**, 29–42 (2017) https://doi.org/10.1016/j.ocecoaman.2017.03.002.
167. Jacob, K. Sea level rise, storm risk, denial, and the future of coastal cities. *Bulletin of the Atomic Scientists* **71**, 40–50 (2015) https://doi.org/10.1177/0096340215599777.
168. Constitución Española. *Título VII. Economía y Hacienda. Artículo 132*. (1978).
169. Jefatura del Estado. *Ley 22/1988, de 28 de julio, de Costas*. vol. BOE-A-1988-18762 23386–23401 (1988).
170. El proceso administrativo del deslinde. *Ministerio para la Transición Ecológica y el Reto Demográfico* https://www.miteco.gob.es/es/agua/temas/delimitacion-y-restauracion-del-dominio-publico-hidraulico/delimitacion-dph-proyecto-linde/proceso-administrativo-deslinde.html [31/05/2024].
171. El varapalo del Supremo a los deslindes del Gobierno no calma a los afectados: 'Es un galimatías jurídico que obligará a revisar caso por caso'. *ELMUNDO* https://www.elmundo.es/economia/2024/02/13/65ca5878e85ece8c4a8b45a1.html [31/05/2024].
172. Hurlimann, A., Barnett, J., Fincher, R., Osbaldiston, N., Mortreux, C. & Graham, S. Urban planning and sustainable adaptation to sea-level rise. *Landscape and Urban Planning* **126**, 84–93 (2014) https://doi.org/10.1016/J.LANDURBPLAN.2013.12.013.
173. Huynh, L. T. M., Su, J., Wang, Q., Stringer, L. C., Switzer, A. D. & Gasparatos, A. Meta-analysis indicates better climate adaptation and mitigation performance of hybrid engineering-natural coastal defence measures. *Nature Communications* **15**, 2870 (2024) https://doi.org/10.1038/s41467-024-46970-w.
174. National Flood and Coastal Erosion Risk Management Strategy for England. *GOV.UK* https://www.gov.uk/government/publications/national-flood-and-coastal-erosion-risk-management-strategy-for-england--2 [02/04/2024].
175. Ministère de l'Environnement, & de l'Énergie et de la Mer. *Stratégie nationale de gestion intégrée du trait de côte Programme d'actions 2017-2019*. https://webissimo.developpement-durable.gouv.fr/IMG/pdf/sngitc_pg2017-2019_web_cle73e4c7.pdf (2017).
176. Morris, R., Konlechner, T., Ghisalberti, M. & Swearer, S. From grey to green: Efficacy of eco‐engineering solutions for nature‐based coastal defence. *Global Change Biology* **24**, 1827–1842 (2018) https://doi.org/10.1111/gcb.14063.
177. Hanson, H. *et al.* Beach nourishment projects, practices, and objectives—a European overview. *Coastal Engineering* **47**, 81–111 (2002) https://doi.org/10.1016/S0378-3839(02)00122-9.
178. Peterson, C. H., Bishop, M. J., Johnson, G. A., D'Anna, L. M. & Manning, L. M. Exploiting beach filling as an unaffordable experiment: Benthic intertidal impacts propagating upwards to shorebirds. *Journal of Experimental Marine Biology and Ecology* **338**, 205–221 (2006) https://doi.org/10.1016/j.jembe.2006.06.021.
179. Parkinson, R. W. & Ogurcak, D. E. Beach nourishment is not a sustainable strategy to mitigate climate change. *Estuarine, Coastal and Shelf Science* **212**, 203–209 (2018) https://doi.org/10.1016/j.ecss.2018.07.011.
180. Escudero, M., Mendoza, E. & Silva, R. Micro Sand Engine Beach Stabilization Strategy at Puerto Morelos, Mexico. *Journal of Marine Science and Engineering* **8**, 247 (2020) https://doi.org/10.3390/jmse8040247.
181. Clipsham, V., Flikweert, J. J., Goodliffe, R., Courtnell, E., Fletcher, A. & Hesk, P. Bacton to Walcott sandscaping, UK: a softer approach to coastal management. *Proceedings of the Institution of Civil Engineers - Civil Engineering* **174**, 49–56 (2021) https://doi.org/10.1680/jcien.20.00064.
182. Ronglan, E. *et al.* Architected materials for artificial reefs to increase storm energy dissipation. *PNAS Nexus* **3**, pgae101 (2024) https://doi.org/10.1093/pnasnexus/pgae101.
183. United Nations Environment Programme. *Nature-based solutions for supporting sustainable development*. https://wedocs.unep.org/xmlui/handle/20.500.11822/39752 (2022).
184. Moraes, R. P. L., Reguero, B. G., Mazarrasa, I., Ricker, M. & Juanes, J. A. Nature-Based Solutions in Coastal and Estuarine Areas of Europe. *Frontiers in Environmental Science* **10**, (2022) https://doi.org/10.3389/fenvs.2022.829526.
185. Sun, Y. Thresholds and Adaptation Pathways of Nature-based Solutions for Sea-level Rise. *Lecture Notes in Education Psychology and Public Media* **21**, 6–13 (2023) https://doi.org/10.54254/2753-7048/21/20230014.
186. Justina, C. R. V. D., Junior, J. L., Ferreira, M. I. P. & Rodrigues, P. P. G. W. Nature based solutions as a promising alternative for river restoration and flood reduction. *Boletim do Observatório Ambiental Alberto Ribeiro Lamego* **13**, 198–212 (2020) https://doi.org/10.19180/2177-4560.v13n22019p198-212.
187. Ferreira, C. S. S., Kalantari, Z., Hartmann, T. & Pereira, P. Introduction: Nature-Based Solutions for Flood Mitigation. *Nature-Based Solutions for Flood Mitigation: Environmental and Socio-Economic Aspects* (eds. Ferreira, C. S. S., Kalantari, Z., Hartmann, T. & Pereira, P.) 1–7 (Springer International Publishing, 2022). ISBN: 978-3-030-77505-6.
188. Möller, I., Spencer, T., French, J. R., Leggett, D. J. & Dixon, M. Wave Transformation Over Salt Marshes: A Field and Numerical Modelling Study from North Norfolk, England. *Estuarine, Coastal and Shelf Science* **49**, 411–426 (1999) https://doi.org/10.1006/ecss.1999.0509.
189. Möller, I. *et al.* Wave attenuation over coastal salt marshes under storm surge conditions. *Nature Geoscience* **7**, 727–731 (2014) https://doi.org/10.1038/ngeo2251.
190. Spek, A. J. F. van der. The development of the tidal basins in the Dutch Wadden Sea until 2100: the impact of accelerated sea-level rise and subsidence on their sediment budget – a synthesis. *Netherlands Journal of Geosciences* **97**, 71–78 (2018) https://doi.org/10.1017/njg.2018.10.
191. Spencer, T. *et al.* Global coastal wetland change under sea-level rise and related stresses: The DIVA Wetland Change Model. *Global and Planetary Change* **139**, 15–30 (2016) https://doi.org/10.1016/j.gloplacha.2015.12.018.
192. Zhu, Z. *et al.* Historic storms and the hidden value of coastal wetlands for nature-based flood defence. *Nature Sustainability* **3**, 853–862 (2020) https://doi.org/10.1038/s41893-020-0556-z.
193. Hanley, M. E. *et al.* Shifting sands? Coastal protection by sand banks, beaches and dunes. *Coastal Engineering* **87**, 136–146 (2014) https://doi.org/10.1016/j.coastaleng.2013.10.020.
194. Laso Bayas, J. C., Marohn, C. & Cadisch, G. Tsunami in the Seychelles: Assessing mitigation mechanisms. *Ocean & Coastal Management* **86**, 42–52 (2013) https://doi.org/10.1016/j.ocecoaman.2013.10.004.
195. Laporte-Fauret, Q., Castelle, B., Michalet, R., Marieu, V., Bujan, S. & Rosebery, D. Morphological and ecological responses of a managed coastal sand dune to experimental notches. *Science of The Total Environment* **782**, 146813 (2021) https://doi.org/10.1016/j.scitotenv.2021.146813.
196. Gómez-Serrano, M. Á. Dune restoration must consider species that need open and early successional dune habitats. *Nature Ecology & Evolution* **8**, 1201–1202 (2024) https://doi.org/10.1038/s41559-024-02441-5.
197. Christianen, M. J. A., Belzen, J. van, Herman, P. M. J., Katwijk, M. M. van, Lamers, L. P. M., Leent, P. J. M. van & Bouma, T. J. Low-Canopy Seagrass Beds Still Provide Important Coastal Protection Services. *PLOS ONE* **8**, e62413 (2013) https://doi.org/10.1371/journal.pone.0062413.
198. Ondiviela, B., Losada, I. J., Lara, J. L., Maza, M., Galván, C., Bouma, T. J. & van Belzen, J. The role of seagrasses in coastal protection in a changing climate. *Coastal Engineering* **87**, 158–168 (2014)

https://doi.org/10.1016/j.coastaleng.2013.11.005.
199. Sánchez-González, J. F., Sánchez-Rojas, V. & Memos, C. D. Wave attenuation due to Posidonia oceanica meadows. *Journal of Hydraulic Research* **49**, 503–514 (2011) https://doi.org/10.1080/00221686.2011.552464.

200. Potouroglou, M. *et al.* Measuring the role of seagrasses in regulating sediment surface elevation. *Scientific Reports* **7**, (2017)
https://doi.org/10.1038/s41598-017-12354-y.
201. Dahl, M. *et al.* A temporal record of microplastic pollution in Mediterranean seagrass soils. *Environmental Pollution* **273**, 116451 (2021)
https://doi.org/10.1016/j.envpol.2021.116451.
202. Lafratta, A., Serrano, O., Masqué, P., Fernandes, M., Gaylard, S. & Lavery, P. S. Seagrass soils sequester up to half the metal emissions of one of the world's largest smelters. *Marine Pollution Bulletin* **197**, 115684 (2023)
https://doi.org/10.1016/j.marpolbul.2023.115684.
203. Apostolaki, E. T., Caviglia, L., Santinelli, V., Cundy, A. B., Tramati, C. D., Mazzola, A. & Vizzini, S. The Importance of Dead Seagrass (Posidonia oceanica) Matte as a Biogeochemical Sink. *Frontiers in Marine Science* **9**, (2022)
https://doi.org/10.3389/fmars.2022.861998.
204. Marbà, N. *et al.* Effectiveness of protection of seagrass (Posidonia oceanica) populations in Cabrera National Park (Spain). (2002)
https://doi.org/10.1017/S037689290200036X.
205. Demers, M.-C. A., Davis, A. R. & Knott, N. A. A comparison of the impact of 'seagrass-friendly' boat mooring systems on *Posidonia australis*. *Marine Environmental Research* **83**, 54–62 (2013)
https://doi.org/10.1016/j.marenvres.2012.10.010.
206. González-Correa, J., Bayle, J., Sánchez-Lizaso, J., Valle, C., Sanchez-Jerez, P. & Ruiz, J. Recovery of deep Posidonia oceanica meadows degraded by trawling. *Journal of Experimental Marine Biology and Ecology* **320**, 65–76 (2005)
https://doi.org/10.1016/J.JEMBE.2004.12.032.
207. *BOE-A-1975-17128 Orden de 30 de julio de 1975 sobre pesca de arrastre en el Mediterráneo.*
208. Jiménez-Casero, J., Belando, M., Bernardeau-Esteller, J., Marín-Guirao, L., García-Muñoz, R., Sánchez-Lizaso, J. & Ruiz, J. A Critical Gap in Seagrass Protection: Impact of Anthropogenic Off-Shore Nutrient Discharges on Deep Posidonia oceanica Meadows. *Plants* **12**, (2023)
https://doi.org/10.3390/plants12030457.
209. Pérez, M., García, T., Invers, O. & Ruiz, J. Physiological responses of the seagrass Posidonia oceanica as indicators of fish farm impact. *Marine pollution bulletin* **56 5**, 869–79 (2008)
https://doi.org/10.1016/j.marpolbul.2008.02.001.
210. González-Correa, J., Torquemada, Y. F. & Lizaso, J. Long-term effect of beach replenishment on natural recovery of shallow Posidonia oceanica meadows. *Estuarine Coastal and Shelf Science* **76**, 834–844 (2008)
https://doi.org/10.1016/J.ECSS.2007.08.012.
211. Pazzaglia, J., Santillán-Sarmiento, A., Helber, S., Ruocco, M., Terlizzi, A., Marín-Guirao, L. & Procaccini, G. Does Warming Enhance the Effects of Eutrophication in the Seagrass Posidonia oceanica? **7**, (2020)
https://doi.org/10.3389/fmars.2020.564805.
212. Dunic, J. C., Brown, C. J., Connolly, R. M., Turschwell, M. P. & Côté, I. M. Long-term declines and recovery of meadow area across the world's seagrass bioregions. *Global Change Biology* **27**, 4096–4109 (2021)
https://doi.org/10.1111/gcb.15684.
213. Roca, G. *et al.* Detecting water quality improvement along the Catalan coast (Spain) using stress-specific biochemical seagrass indicators. *Ecological Indicators* **54**, 161–170 (2015)
https://doi.org/10.1016/j.ecolind.2015.02.031.
214. de los Santos, C. B. *et al.* Recent trend reversal for declining European seagrass meadows. *Nature Communications* **10**, 3356 (2019)
https://doi.org/10.1038/s41467-019-11340-4.
215. Calvo, S., Calvo, R., Luzzu, F., Raimondi, V., Assenzo, M., Cassetti, F. P. & Tomasello, A. Performance Assessment of Posidonia oceanica (L.) Delile Restoration Experiment on Dead matte Twelve Years after Planting—Structural and Functional Meadow Features. *Water* (2021)
https://doi.org/10.3390/W13050724.
216. Macreadie, P. I. *et al.* Blue carbon as a natural climate solution. *Nature Reviews Earth & Environment* **2**, 826–839 (2021)
https://doi.org/10.1038/s43017-021-00224-1.
217. Azar, C., Johansson, D. J. A. & Mattsson, N. Meeting global temperature targets—the role of bioenergy with carbon capture and storage. *Environmental Research Letters* **8**, 034004 (2013)
https://doi.org/10.1088/1748-9326/8/3/034004.
218. Snæbjörnsdóttir, S. Ó., Sigfússon, B., Marieni, C., Goldberg, D., Gislason, S. R. & Oelkers, E. H. Carbon dioxide storage through mineral carbonation. *Nature Reviews Earth & Environment* **1**, 90–102 (2020)
https://doi.org/10.1038/s43017-019-0011-8.
219. Gattuso, J.-P., Williamson, P., Duarte, C. M. & Magnan, A. K. The Potential for Ocean-Based Climate Action: Negative Emissions Technologies and Beyond. *Frontiers in Climate* **2**, (2021)
https://doi.org/10.3389/fclim.2020.575716.
220. Johannessen, S. C. & Macdonald, R. W. Geoengineering with seagrasses: is credit due where credit is given? *Environmental Research Letters* **11**, 113001 (2016)
https://doi.org/10.1088/1748-9326/11/11/113001.
221. Johannessen, S. C. & Christian, J. R. Why blue carbon cannot truly offset fossil fuel emissions. *Communications Earth & Environment* **4**, 1–4 (2023)
https://doi.org/10.1038/s43247-023-01068-x.
222. forumnatura.eu. La Ley de Costas: amenaza o realidad ante impactos climáticos.
https://forumnatura.org/2024/04/04/la-ley-de-costas-amenaza-o-realidad-ante-impactos-climaticos/ [13/07/2024].
223. EFE. Canarias se harta de los excesos del turismo y se echa a la calle para protestar. *elEconomista.es*
https://www.eleconomista.es/transportes-turismo/noticias/12778675/04/24/canarias-se-harta-de-los-excesos-del-turismo-y-se-echa-a-la-calle-para-protestar.html [30/05/2024].
224. Miles de personas protestan en Canarias contra el turismo de masas: 'Las islas tienen un límite'.
https://www.publico.es/sociedad/marea-humana-protesta-calles-turismo-masas-canarias-limite.html [30/05/2024].
225. Powis, C. M., Byrne, D., Zobel, Z., Gassert, K. N., Lute, A. C. & Schwalm, C. R. Observational and model evidence together support wide-spread exposure to noncompensable heat under continued global warming. *Science Advances* **9**, eadg9297 (2023)
https://doi.org/10.1126/sciadv.adg9297.
226. Raymond, C., Matthews, T. & Horton, R. M. The emergence of heat and humidity too severe for human tolerance. *Science Advances* **6**, eaaw1838 (2020)
https://doi.org/10.1126/sciadv.aaw1838.
227. Amelung, B. & Viner, D. Mediterranean Tourism: Exploring the Future with the Tourism Climatic Index. *Journal of Sustainable Tourism* **14**, 349–366 (2006)
https://doi.org/10.2167/jost549.0.
228. Bujosa, A., Riera, A. & Torres, C. M. Valuing tourism demand attributes to guide climate change adaptation measures efficiently: The case of the Spanish domestic travel market. *Tourism Management* **47**, 233–239 (2015)
https://doi.org/10.1016/j.tourman.2014.09.023.
229. Bujosa, A. & Rosselló, J. Climate change and summer mass tourism: the case of Spanish domestic tourism. *Climatic Change* **117**, 363–375 (2013)
https://doi.org/10.1007/s10584-012-0554-x.
230. Coombes, E., Jones, A. & Sutherland, W. The Implications of Climate Change on Coastal Visitor Numbers: A Regional Analysis. 981–990 (2009)
https://doi.org/10.2112/07-0993.1.
231. Bombana, B., Santos-Lacueva, R. & Saladié, Ò. Will Climate Change Affect the Attractiveness of Beaches? Beach Users' Perceptions in Catalonia (NW Mediterranean). *Sustainability* **15**, 7805 (2023)
https://doi.org/10.3390/su15107805.
232. Femenias Rosselló, L. B., Bujosa Bestard, A. & Riera Font, A. Is carbon footprint reduction always preferred over offsetting? An analysis of tourists' preferences in the Mallorca region. *Economic Analysis and Policy* **81**, 1371–1381 (2024)
https://doi.org/10.1016/j.eap.2024.02.018.
233. Ministerio para la Transición Ecológica y el Reto Demográfico. Plan Nacional de Adaptación al Cambio Climático (2021-2030). (2021).
234. Ministerio de Industria y Turismo - Estrategia de Turismo Sostenible de España 2030.
https://turismo.gob.es/es-es/estrategia-turismo-sostenible/paginas/index.aspx [30/05/2024].
235. Martín, J. M. M., Aguilera, J. D. D. J. & Moreno, V. M. Impacts of Seasonality on Environmental Sustainability in the Tourism Sector Based on Destination Type: An Application to Spain'S Andalusia Region. *Tourism Economics* **20**, 123–142 (2014)
https://doi.org/10.5367/te.2013.0256.
236. Save Posidonia Project - Formentera. //www.savepos idoniaproject.org/en/sobre-el-proyecto/ [30/05/2024].
237. Xunta de Galicia. *DECRETO 177/2018, de 27 de diciembre, por el que se aprueba el Plan rector de uso y gestión del Parque Nacional Marítimo-Terrestre de las Islas Atlánticas de Galicia.*
https://www.xunta.gal/dog/Publicados/2019/20190218/AnuncioG0532-280119-0002_es.html (2019).
238. Rodríguez-Pérez de Arenaza, D., Hierro, L. Á. & Patiño, D. Airbnb, sun-and-beach tourism and residential rental prices. The case of the coast of Andalusia (Spain). *Current Issues in Tourism* **25**, 3261–3278 (2022)
https://doi.org/10.1080/13683500.2019.1705768.
239. Vera-Rebollo, J. F. & Ivars-Baidal, J. Measuring sustainability in a mass tourist destination: pressures, perceptions and policy responses in Torrevieja, Spain. (2003)
https://doi.org/10.1080/09669580308667202.
240. Gomis, D. & Álvarez Fanjul, E. *Vulnerabilidad de los puertos españoles ante el cambio climático. Vol. 1: Tendencias de variables físicas oceánicas y atmosféricas durante las últimas décadas y proyecciones para el siglo XXI.*
https://www.puertos.es/es-es/_layouts/download.aspx?SourceUrl=/es-es/BibliotecaV2/VULNERABILIDAD_completo_alta.pdf (2016).
241. Gracia, V., Sierra, J. P., Gómez, M., Pedrol, M., Sampé, S., García-León, M. & Gironella, X. Assessing the impact of sea level rise on port operability using LiDAR-derived digital elevation models. *Remote Sensing of Environment* (2019)
https://doi.org/10.1016/J.RSE.2019.111318.
242. Christodoulou, A., Christidis, P. & Demirel, H. Sea-level rise in ports: a wider focus on impacts. *Maritime Economics & Logistics* 1–15 (2018)
https://doi.org/10.1057/S41278-018-0114-Z.
243. Hanson, S. & Nicholls, R. Demand for Ports to 2050: Climate Policy, Growing Trade and the Impacts of Sea-Level Rise. *Earth's Future* **8**, (2020)
https://doi.org/10.1029/2020EF001543.
244. Sierra, J. P. Economic Impact of Overtopping and Adaptation Measures in Catalan Ports Due to Sea Level Rise. *Water* **11**, 1440 (2019)
https://doi.org/10.3390/w11071440.
245. Puertos del Estado. *Estrategia de sostenibilidad de Puertos del Estado.*
https://www.puertos.es/es-es/medioambiente .
246. Puertos del Estado. *Estrategia de sostenibilidad del sistema portuario. Contribuir a mejorar la calidad del agua y de los sedimentos de los puertos.*
https://www.puertos.es/es-es/medioambiente/Documents/Transporte%20Sostenible%2010%20-%20Calidad%20Agua.pdf (2010).
247. BOE-A-2022-17512 Orden TMA/1014/2022, de 7 de octubre, por la que se aprueba el Marco Estratégico del sistema portuario de interés general.
248. Urban Klima 2050. Adaptación de los puertos.
https://urbanklima2050.eu/es/adaptacion-de-los-puertos/accion/18/ [13/07/2024].

249. Blasco Díaz, J. L. La distribución competencial en materia de costas. Revista d'estudis autonòmics i federals 245–285 (2010).
250. Menéndez Rexach, Á. La distribución de competencias en la Ley de costas y la gestión integrada del litoral. Estudios sobre la ordenación, planificación y gestión del litoral: hacia un modelo integrado y sostenible, 2009, ISBN 978-84-95892-79-9, págs. 119-129 119–129 (2009).
251. Ministerio de Agricultura, Alimentación y Medio Ambiente. Real Decreto 876/2014, de 10 de octubre, por el que se aprueba el Reglamento General de Costas. vol. BOE-A-2014-10345 83098–83216 (2014).
252. Jefatura del Estado. Ley 2/2013, de 29 de mayo, de protección y uso sostenible del litoral y de modificación de la Ley 22/1988, de 28 de julio, de Costas. vol. BOE-A-2013-5670 40691–40736 (2013).
253. Ministerio de Política Territorial. Real Decreto 713/2022, de 30 de agosto, de traspaso de funciones y servicios de la Administración General del Estado a la Comunidad Autónoma de Canarias en materia de ordenación y gestión del litoral. vol. BOE-A-2022-14778 125207–125217 (2022).
254. Ministerio de Política Territorial. Real Decreto 994/2022, de 29 de noviembre, de traspaso de funciones y servicios de la Administración del Estado a la Comunidad Autónoma de las Illes Balears en materia de ordenación y gestión del litoral. vol. BOE-A-2022-20275 165717–165728 (2022).
255. Ministerio de Política Territorial y Administración Pública. Real Decreto 62/2011, de 21 de enero, sobre traspaso de funciones y servicios de la Administración del Estado a la Comunidad Autónoma de Andalucía en materia de ordenación y gestión del litoral. vol. BOE-A-2011-2617 14580–14591 (2011).
256. Xunta de Galicia. La Xunta solicita al Estado el traspaso de las funciones y servicios necesarios para poder asumir la gestión completa de su litoral. https://www.xunta.gal/notas-de-prensa/-/nova/001657/xunta-solicita-estado-traspaso-las-funciones-servicios-necesarios-para-poder?langId=es_ES [09/09/2024].
257. Comunidad Autónoma de Galicia. Ley 4/2023, de 6 de julio, de ordenación y gestión integrada del litoral de Galicia. vol. BOE-A-2023-19356 124490–124541 (2023).
258. Ministerio de Administraciones Públicas. Real Decreto 1387/2008, de 1 de agosto, sobre ampliación de funciones y servicios traspasados a la Generalitat de Cataluña por Real Decreto 1404/2007, de 29 de octubre, en materia de ordenación y gestión del litoral. vol. BOE-A-2008-14858 37180–37185 (2008).
259. Tribunal Constitucional. Pleno. Sentencia 68/2024, de 23 de abril de 2024. Recurso de inconstitucionalidad 6521-2023. Interpuesto por el presidente del Gobierno respecto de la Ley del Parlamento de Galicia 4/2023, de 6 de julio, de ordenación y gestión integrada del litoral de Galicia. Competencias sobre el dominio público marítimo terrestre: nulidad parcial de los preceptos relativos a la garantía del acceso y permanencia de las embarcaciones gallegas en los caladeros de competencia autonómica y a la ocupación del dominio público marítimo terrestre por los sistemas de recogida, almacenamiento, tratamiento y vertido de aguas residuales; interpretación conforme con la Constitución del precepto legal autonómico que prevé la ocupación por establecimientos de la cadena mar-industria alimentaria del demanio o de la zona de servidumbre de protección. Voto particular. 63032–63144.
260. Jefatura del Estado. Ley 42/2007, de 13 de diciembre, del Patrimonio Natural y de la Biodiversidad. vol. BOE-A-2007-21490 51275–51327 (2007).
261. Jefatura del Estado. Ley 21/2013, de 9 de diciembre, de evaluación ambiental. vol. BOE-A-2013-12913 98151–98227 (2013).
262. Ministerio de Fomento. Real Decreto Legislativo 2/2011, de 5 de septiembre, por el que se aprueba el Texto Refundido de la Ley de Puertos del Estado y de la Marina Mercante. vol. BOE-A-2011-16467 109456–109710 (2011).
263. Jefatura del Estado. Ley 5/2023, de 17 de marzo, de pesca sostenible e investigación pesquera. vol. BOE-A-2023-7052 40658–40705 (2023).
264. Costas y Medio Marino. Ministerio para la Transición Ecológica y el Reto Demográfico https://www.miteco.gob.es/es/costas/temas.html [18/04/2024].
265. Directiva 2007/60/CE del Parlamento Europeo y del Consejo, de 23 de octubre de 2007 , relativa a la evaluación y gestión de los riesgos de inundación (Texto pertinente a efectos del EEE). OJ L vol. 288 (2007).
266. de Andrés, M., Barragán, J. M., Arenas Granados, P., García Sanabria, J. & García Onetti, J. Gestión de las Zonas Costeras y Marinas en España. Revista Costas 1, 117–132 (2020) https://doi.org/10.26359/costas.e106.
267. Ministerio de Agricultura y Pesca, Alimentación y Medio Ambiente & Dirección general de sostenibilidad de la costa y el mar. Estrategia de Adaptación al Cambio Climático de la Costa Española. https://www.miteco.gob.es/content/dam/miteco/es/costas/temas/proteccion-costa/estrategiaadaptacionccaprobada_tcm30-420088.pdf (2016).
268. Servicio provincial de costas en Alicante, Rodríguez, A. M., Solchaga Elizalde, O., Cobos Campos, G., & Ministerio para la Transición Ecológica y el Reto Demográfico. PIMA ADAPTA. Conocimiento y acción frente a los riesgos derivados del cambio climático. https://www.miteco.gob.es/content/dam/miteco/es/cambio-climatico/planes-y-estrategias/pimaadapta2020_tcm30-521929.pdf (2020).
269. PIMA Adapta Costas Canarias. https://pimacostas.grafcan.es/ [26/06/2024].
270. Sanz Larruga, F. J. La protección ambiental del litoral español: hacia una gestión sostenible e integrada de las zonas costeras. Anuario da Facultade de Dereito da Universidade da Coruña 459–486 (2000).
271. Greenpeace. 30 años de la Ley de Costas ¿Qué nos ha dejado? Greenpeace España https://es.greenpeace.org/es/noticias/30-anos-de-la-ley-de-costas-que-nos-ha-dejado/ [02/07/2024].
272. Carro Fernández-Valmayor, J. L., Ferreira Fernández, A. J., Nogueira López, A., Carro Fernández-Valmayor, J. L., Ferreira Fernández, A. J. & Nogueira López, A. La nueva regulación de las costas: actas del IX Congreso de la Asociación Española de Profesores de Derecho Administrativo, Santiago de Compostela, 7 y 8 de febrero de 2014. La nueva regulación de las costas: actas del IX Congreso de la Asociación Española de Profesores de Derecho Administrativo, Santiago de Compostela, 7 y 8 de febrero de 2014 (Madrid: Instituto Nacional de Administración Pública, 2014). ISBN: 978-84-7351-336-4.
273. Roselló, M. R. Z. Legislación de costas y planificación urbanística: NÚÑEZ LOZANO, María del Carmen, Legislación de costas y planificación urbanística, Cuadernos Universitarios de Derecho Administrativo, Edit. Derecho Global, Sevilla, 2009, 266 págs. Prólogo de D. Ángel Menéndez Rexach. Revista Andaluza de Administración Pública 485–489 (2010) https://doi.org/10.46735/raap.n77.652.
274. La asociación en defensa del litoral de la Comunidad Valenciana 'Mediterránea' suma ya 30 colectivos. El Español https://www.elespanol.com/alicante/20220322/asociacion-defensa-litoral-comunidad-valenciana-mediterranea-colectivos/658934382_0.html [03/07/2024].
275. Boletín Oficial de las Cortes Generales. Senado. Proposición de Ley relativa a la modificación de la Ley 22/1988, de 28 de julio, de Costas, para permitir la pervivencia de conjuntos urbanos costeros de tipología tradicional en terrenos que han pasado a ser de dominio público marítimo-terrestre. (2024).
276. Desdentado Daroca, E. La expropiación de los enclaves privados en el litoral: (una crítica de la Disposición Transitoria 1a de la Ley de Costas). (2007). ISBN: 978-84-470-2790-3.
277. Desdentado Daroca, E. Los enclaves privados tras el Reglamento de Costas de 2014 y la última jurisprudencia. Revista General de Derecho Administrativo 16 (2018).
278. Greenpeace España. A toda costa. Análisis de los ecosistemas naturales costeros vulnerables a la urbanización masiva del litoral. https://es.greenpeace.org/es/wp-content/uploads/sites/3/2019/06/Costas-2019-completo-ver2.pdf (2019).
279. Tribunal Constitucional. Pleno. Sentencia 25/2024, de 13 de febrero de 2024. Recurso de inconstitucionalidad 1413-2022. Interpuesto por más de cincuenta diputados pertenecientes a los grupos parlamentarios Confederal Unidas Podemos-En Comú Podem-Galicia en Común, Republicano, Plural y Grupo Mixto del Congreso de los Diputados en relación con la Ley del Parlamento de Andalucía 7/2021, de 1 de diciembre, de impulso para la sostenibilidad del territorio de Andalucía. Principios democrático, de igualdad, legalidad y no discriminación, de seguridad jurídica y autonomía local; interdicción de la arbitrariedad y no regresión ambiental; derecho al ejercicio de las funciones representativas; competencias de protección ambiental: nulidad parcial de los preceptos autonómicos que permiten la edificación residencial en suelo rústico y la desafectación de vías pecuarias sujetas a planeamiento urbanístico y eximen a los usos mineros del requisito de licencia urbanística; interpretación conforme de los preceptos legales relativos a las actuaciones y usos ordinarios del suelo rústico. vol. BOE-A-2024-5836 33945–34000 (2024).
280. Tribunal Constitucional. *Pleno. Sentencia 149/1991 , de 4 de julio. Recursos de inconstitucionalidad 1.689/1988, 1.708/1988, 1.711/1988, 1.715/1988, 1.717/1988, 1.723/1988, 1.728/1988, 1.729/1988 y 1.740/1988 (acumulados). Interpuestos por la Xunta de Galicia, el Consejo de Gobierno de las Islas Baleares, el Gobierno Vasco, el Parlamento de Cataluña, el Consejo del Gobierno de la Diputación Regional de Cantabria, el Consejo Ejecutivo de la Generalidad de Cataluña, el Gobierno de Canarias, el Gobierno Valenciano y un grupo de 50 Diputados, contra la Ley 22/1988, de 28 de julio, de Costas*. vol. BOE-T-1991-19353 14–53 (1991).
281. López-Gutiérrez, J. S., Negro, V. & Esteban, M. D. New Coastal Regulation in Spain. A roadmap to a better approach to coastal environment. Journal of Coastal Research 75, 662–666 (2016) https://doi.org/10.2112/SI75-132.1.
282. Ministerio para la Transición Ecológica y el Reto Demográfico. Consulta pública previa sobre el Proyecto de Real Decreto por el que se modificaría el Real Decreto 876/2014, de 10 de octubre, por el que se aprobó el Reglamento General de Costas. (2024).
283. Greenpeace. Greenpeace aplaude la reforma del reglamento de la Ley de Costas y contribuye con la presentación de alegaciones. Greenpeace España https://es.greenpeace.org/es/sala-de-prensa/comunicados/greenpeace-aplaude-la-reforma-del-reglamento-de-la-ley-de-costas-y-contribuye-con-la-presentacion-de-alegaciones/ [02/07/2024].
284. Directiva 2008/56/CE del Parlamento Europeo y del Consejo, de 17 de junio de 2008, por la que se establece un marco de acción comunitaria para la política del medio marino (Directiva marco sobre la estrategia marina). https://www.boe.es/buscar/doc.php?id=DOUE-L-2008-81148 (2008).
285. Jefatura del Estado. Ley 41/2010, de 29 de diciembre, de protección del medio marino. vol. BOE-A-2010-20050 108464–108488 (2010).
286. Ministerio para la Transición Ecológica y el Reto Demográfico. Real Decreto 150/2023, de 28 de febrero, por el que se aprueban los planes de ordenación del espacio marítimo de las cinco demarcaciones marinas españolas. vol. BOE-A-2023-5704 32350–32578 (2023).
287. Directiva 2014/89/UE del Parlamento Europeo y del Consejo, de 23 de julio de 2014, por la que se establece un marco para la ordenación del espacio marítimo. https://www.boe.es/buscar/doc.php?id=DOUE-L-2014-81825 (2014).
288. Directiva 2000/60/CE del Parlamento Europeo y del Consejo, de 23 de octubre de 2000, por la que se establece un marco comunitario de actuación en el ámbito de la política de aguas. https://www.boe.es/buscar/doc.php?id=DOUE-L-2000-82524 (2000).

289. Ministerio de Medio Ambiente. Real Decreto Legislativo 1/2001, de 20 de julio, por el que se aprueba el texto refundido de la Ley de Aguas. vol. BOE-A-2001-14276 26791–26817 (2001).
290. Sardá, R., Avila, C. & Mora, J. A methodological approach to be used in integrated coastal zone management processes: the case of the Catalan Coast (Catalonia, Spain). Estuarine, Coastal and Shelf Science 62, 427–439 (2005) https://doi.org/10.1016/j.ecss.2004.09.028.
291. Lozoya, J. P., Sardá, R. & Jiménez, J. A. Users expectations and the need for differential beach management frameworks along the Costa Brava: Urban vs. natural protected beaches. Land Use Policy 38, 397–414 (2014) https://doi.org/10.1016/j.landusepol.2013.12.001.
292. Sagristà, E., Sardá, R. & Serra, J. Consecuencias a Largo Plazo de la Gestión Desintegrada en Zonas Costeras: el Caso del Delta de la Tordera (Cataluña, España). Costas Vol. 1, no 1 (2019), 1-22 (2018) https://doi.org/10.26359/costas.0101.
293. Rodríguez Fernández-Blanco, C. Unravelling the role of social innovation for fostering socio-ecological resilience in Mediterranean, fire-prone territories. (Leuven Universitet, 2023).
294. Brenner, J., Jiménez, J. A., Sardá, R. & Garola, A. An assessment of the non-market value of the ecosystem services provided by the Catalan coastal zone, Spain. Ocean & Coastal Management 53, 27–38 (2010) https://doi.org/10.1016/j.ocecoaman.2009.10.008.
295. Huynh, L. T. M., Gasparatos, A., Su, J., Dam Lam, R., Grant, E. I. & Fukushi, K. Linking the nonmaterial dimensions of human-nature relations and human well-being through cultural ecosystem services. Science Advances 8, eabn8042 (2022) https://doi.org/10.1126/sciadv.abn8042.
296. Autoridad Portuaria de Huelva. Ecological recovery in the Port of Huelva. https://sustainableworldports.org/wp-content/uploads/Project-report.pdf (2020).
297. Curado, G., Manzano-Arrondo, V., Figueroa, E. & Castillo, j. M. Public Perceptions and Uses of Natural and Restored Salt Marshes. Landscape Research 39, 668–679 (2014) https://doi.org/10.1080/01426397.2013.772960.
298. The worldwide network of port cities. PLAN THE CITY WITH THE PORT. Guide of good practices. (2021).
299. Oficina Estratègica de l'Àmbit Litoral, Gerència Municipal, & S. A. Barcelona Regional Agència de Desenvolupament Urbà. Pla Litoral : Pla estratègic dels espais litorals de la ciutat. (2019).
300. Ajuntament de Barcelona & Gerència d'arquitecte en cap. Passeig Marítim de la Mar Bella. https://www.barcelona.cat/plalitoral/sites/default/files/2022-10/56.%20Presentaci%C3%B3%20avantprojecte%20Ps%20MarBella%2020210930.pdf (2021).
301. Llum verda a la transformació del passeig Marítim de la Mar Bella en un nou espai verd i de foment de l'esport : Servei de Premsa. https://ajuntament.barcelona.cat/premsa/2023/09/19/llum-verda-a-la-transformacio-del-passeig-maritim-de-la-mar-bella-en-un-nou-espai-verd-i-de-foment-de-lesport/ [16/07/2024].
302. Fernández-Mora, A., Criado-Sudau, F. F., Gómez-Pujol, L., Tintoré, J. & Orfila, A. Ten years of morphodynamic data at a micro-tidal urban beach: Cala Millor (Western Mediterranean Sea). Scientific Data 10, 301 (2023) https://doi.org/10.1038/s41597-023-02210-2.
303. LIFE AdaptCalaMillor-El proyecto. https://www.caib.es/sites/adaptcalamillor/es/portada_dg/?campa=yes [05/07/2024].
304. El Proyecto. LIFE Garachico https://lifegarachico.eu/el-proyecto/ [25/09/2024].
305. Lara, J. L., Eulate, M. F. A. D., Tomás, A., Fernandez, A. & Lucio, D. Enhancing Coastal Flooding Preparedness To Climate Change: An Experimental Analysis Of Urban-Integrated Non-Conventional Adaptation Solutions. CoastLab 2024: Physical Modelling in Coastal Engineering and Science (2024) https://doi.org/10.59490/coastlab.2024.795.