Journal of
Marine Science and Engineering

MDPI

Review

Main Threats in Mediterranean Coastal Wetlands. The Ebro Delta Case

Inmaculada Rodríguez-Santalla and Nuria Navarro *

Departamento de Biología, Geología, Física y Química Inorgánica, ESCET, Universidad Rey Juan Carlos, C/Tulipán s/n, 28933 Madrid, Spain; inmaculada.rodriguez@urjc.es
* Correspondence: nuria.navarro@urjc.es

Abstract: Coastal wetlands are dynamic ecosystems that exist at the interface between land and sea. They represent environments with a great diversity of habitats and communities, high carbon sequestration capacity and a wide range of ecosystem services. In the Mediterranean, the largest coastal wetlands are found in deltaic areas like that of the Ebro River (Spain), which has a coastline length of approximately 50 km, occupying a total area of 325 km^2. The Ebro Delta is included in different national and international frameworks for environmental conservation, despite which there are several risks that threaten it. The lack of sedimentary contributions due to the regulation of the Ebro riverbed (irrigation, reservoirs, and hydroelectric power generation) has caused erosion and the retreat of certain sections of its coastline. To this situation of sediment deficit must be added the threat posed by the effects of global change, such as the rise in sea level, the increase in temperature and in the frequency and intensity of storms. This study analyses the particularities of the coastal wetland of the Ebro Delta, identifying the main threats it faces, as well as possible adaptation and mitigation strategies to these changes.

Keywords: deltas; sedimentation decrease; coastal lagoons; global change; Mediterranean wetlands; Ebro Delta

Citation: Rodríguez-Santalla, I.; Navarro, N. Main Threats in Mediterranean Coastal Wetlands. The Ebro Delta Case. *J. Mar. Sci. Eng.* **2021**, *9*, 1190. https://doi.org/10.3390/jmse9111190

Academic Editor: Edward J. Anthony

Received: 14 September 2021
Accepted: 21 October 2021
Published: 27 October 2021

1. Introduction

The Ramsar Convention [1] considers wetlands as one of the key life support systems on this planet, as they represent a decisive factor in conserving the biodiversity of fresh inland waters and inland waters' coastal eco-systems. It highlights its importance as a vital element of ecosystems, representing the habitat of many threatened plant and animal species, as well as for national and global economies. Wetlands include mangroves, other coastal ecosystems such as strand forests, beach vegetation, salt marshes, deltas, and estuaries and terrestrial wetlands such as swamp forests, marshes, bogs, and in the broad sense even lakes and streams [2].

In coastal wetlands, the mixture between continental water and marine water occurs, which is why they represent environments with a great primary production and diversity of habitats and communities [2], and with an exceptional capacity as carbon sinks [3]. These ecosystems are recognized for their large organic carbon stocks and carbon sequestration capacity, as well as for providing a wide range of other ecosystem services, such as supporting fisheries, biodiversity, agriculture, coastal protection, and climate mitigation [4,5]. This increasing appreciation, combined with the growing threats to these ecosystems, has given rise to the development of blue carbon strategies [6,7]. According Williams [8], wetlands have been altered radically as they have been drained for intensive agriculture, or used as dumping grounds for waste, and the creation of industrial and residential land. Legislation for the protection of wetlands has been strongest in the United States, somewhat less so elsewhere in the developed world, and almost non-existent in the developing world, where food production is paramount. Mójica-Velez et al. [9] reviewed the key challenges of coastal wetlands policies over the last few years, finding that development policies are affecting coastal wetlands by promoting or allowing urban and economic activities to grow out of control; territorial planning is mismatched with ecological dynamics and influenced by economic interests.

In the Mediterranean, the largest coastal wetlands are found in delta areas like that of the Rhône (France), Nile (Egypt), Po (Italy) and Ebro (Spain) rivers [10]. The deltaic areas represent the most vulnerable coastal areas, whose elevation barely exceeds a few meters in height. Deltas are subject to the interacting effects of rivers, seas, lands, and atmospheric factors and, therefore, will be affected by diverse drivers associated with climate change [11]. Sea-level rise is already considered as an important issue in deltaic areas [12]. Other drivers are affecting deltaic behaviour such as increases in inundation/flooding, coastal erosion, extreme events, sedimentation decrease, salinity intrusion and degradation of some habitats [13]. Mediterranean deltas have been strongly modified by human activities [14]. Different economic activities are developed, especially agricultural because the river sediment provides nutrients and textural balance to the soil, favouring its development and improving its fertility [10]. In the last 150 years, the Ebro delta has been transformed into rice fields, which now cover around 70% of the total area [15], while natural areas, including coastal lagoons and wetlands, cover about 80 km^2 [14]. Agricultural activities necessitate controlling water and sediment inputs from the Ebro River, further affecting the natural areas [15]. These modifications in its structure and functioning have made the Ebro Delta even more vulnerable to the threats of global change.

This article aims to review the particularities of the coastal wetland of the Ebro Delta (Spain), identifying the main threats it faces, as well as possible adaptation and mitigation strategies to these changes.

2. Study Site

The Ebro Delta, located in the Western Mediterranean (Catalonia, Spain) (Figure 1), is Spain's second most important wetland after Doñana (Atlantic coast of Andalusia, Spain). It is a wetland of significant environmental value due to its great diversity of habitats, such as marshes, coastal lagoons, river, sea, beaches and dunes, freshwater springs, etc. It is home to a rich biodiversity, for example, there are around 360 of the 600 birds in Europe, which use the Ebro delta for nesting, wintering and as a resting area during their migrations [16]; therefore, it is the second most important 'Special Protection Area' for birds in Spain [10]. There are also different species of reptiles, fish, and invertebrates, especially the bivalve *Pinna nobilis*, which is in critical danger of extinction (included in the red list of endangered species of the International Union for Conservation of Nature—IUCN). The Ebro Delta is included in the different national and international frameworks for environmental conservation: International Interest of Euro-African Wetlands, category A—urgent priority (UNESCO, 1962); wetland of international importance (Ramsar Convention, 1971); special protection area for birds ZEPA (European Union, 1979); Natural Park (Spain, 1983); Natura 2000 Network (European Union, 1992).

The Holocene Ebro River Delta is basically a silty plain 4 to 5 m above sea level, being the river channels and external coastal front the only sandy domains [17]. It has a coastline length of approximately 50 km, occupying a total area of 325 km^2 which represents only 15% of the 2171 total km^2 that forms the delta [18]. According to Sierra et al. [19], the climate is Mediterranean with temperatures seldom higher than 35 °C or lower than 0 °C, the annual average temperature being 16.2 °C, with a monthly maximum average of 24.2 °C in August and a minimum of 9 °C in January. The yearly average rainfall is 530 L/m^2, very irregularly distributed, with 408 L/m^2 (77%) in the wet season (spring and autumn) and 122 L/m^2 (23%) in the dry season (winter and summer). The river's mean annual flow in Tortosa (18 km from Amposta, Figure 1) is 431 m^3 s $^{-1}$ [20]. According to Vericat and Batalla [21], annual total load downstream from the dams is estimated at around $0.45 \cdot 10^6$ t, of which 60% is transported in suspension and the remaining 40% as bedload (mean D_{50} in the range of 32 mm). Wind climate shows a strong seasonal pattern: during fall and winter there is a clear predominance of northern and north-western winds, while in spring prevailing winds are from the east and during summer dominant ones are from the south [22]. A general or global wind rose (data from 2021) is presented in Figure 1 showing how the northern components reach greatest intensity. The wave climate in this area has also a very defined seasonal structure with low energy wave conditions from June to September, energetic wave conditions from October to March and transition conditions the rest of the year [19]. The wind-generated waves in the Ebro Delta come basically from three directions: the sectors from NE to E, S and NW. In terms of the wave energy flux, the eastern components (eastern and east-northeastern) are clearly dominant, corresponding with the highest number of storms (Figure 1), and where, for the northern Spanish Mediterranean coast, coincide the largest fetches and the stronger winds [23]. The Ebro Delta has a microtidal regime, characterized by maximum astronomical and meteorological tides of 0.20 to 0.25 m and 1 m, respectively [24].

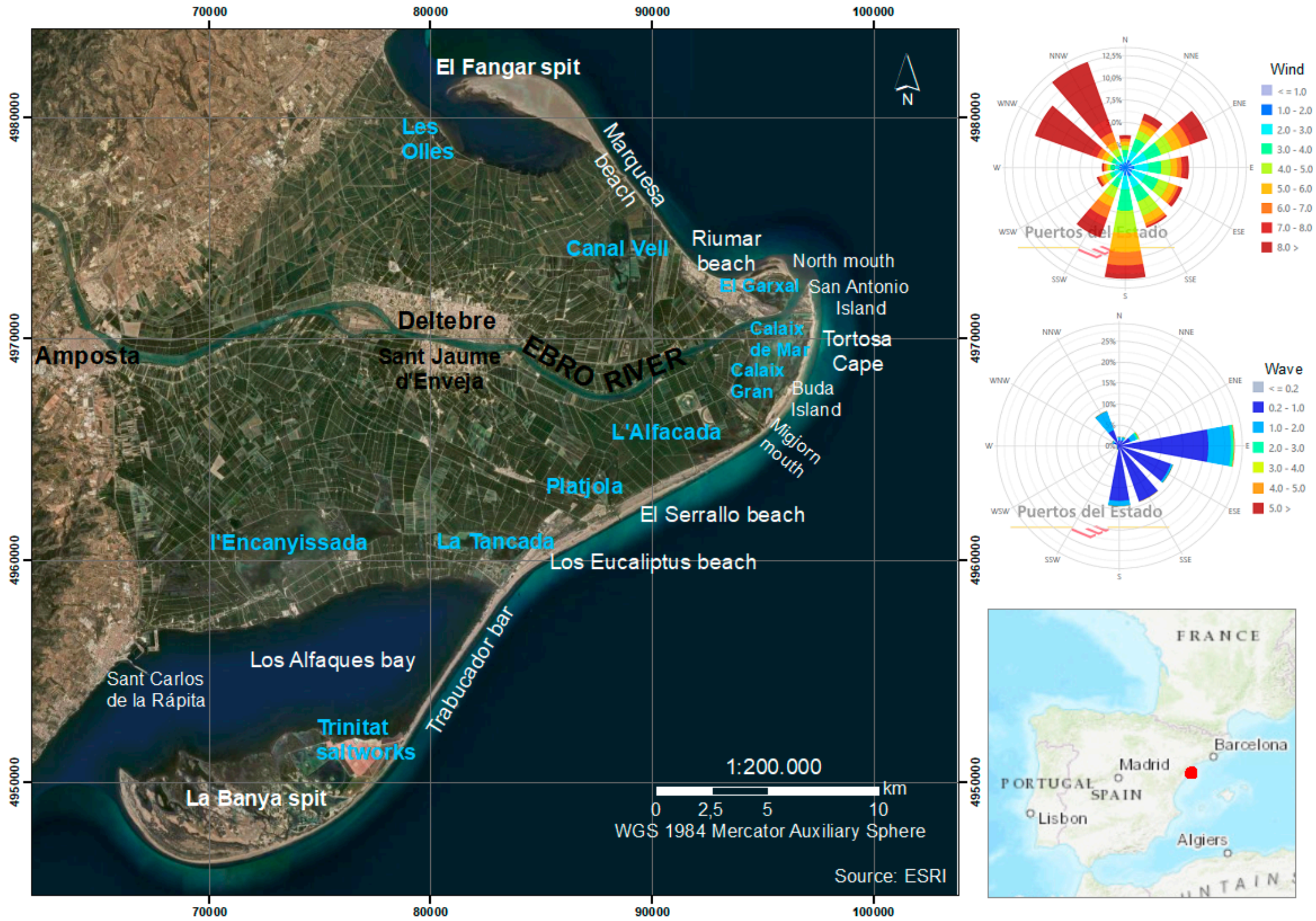

Figure 1. Location of the main geomorphologic elements. The lagoons are represented in blue. The wind rose (average wind speed (m/s)) and the wave rose (significant wave height (m)) are displayed on the right. Source: Puertos del Estado (www.puertos.es/es-es (accessed on 5 October 2021)).

The current morphological configuration is established by two hemideltas separated by the Ebro River. On both hemideltas two spits are developed, which partially close the lagoons of El Fangar (located in the north) and Los Alfaques (to the south), which is joined to the deltaic body through the Trabucador bar which is 4 km long and about 200 m wide [24]. Figure 1 shows a distribution of geomorphologic elements developed in Ebro Delta. An extensive description of these singularities is provided in [25–28]. Figures 2–4 show photographs of the different natural environments developed in Ebro Delta.

Both hemideltas present dune activity, but even though they belong to the same deltaic sedimentary system, the dune fields present in them show very different characteristics that indicate environmental differences between both zones; the dune field of the north hemidelta is very dynamic, while in the south hemidelta the dunes show less activity and are colonized by vegetation [29]. A review of the field dune system of Ebro Delta can be found in [22,29–32].

The rapid geological evolution of Ebro Delta has given rise to the formation of coastal lagoons (Figure 1) resulting from the delimitation of coastal environments by sand bars, which remain in more interior positions of the deltaic plain as the delta has been prograding. According to the Ramsar program, the lagoons of the Ebro Delta are classified as coastal brackish/saline lagoons (site J) [33], and considered "priority habitats" under the EU Habitats Directive [34]. These are very shallow, and the average depth is lower than 50 cm; only the l'Encanyisada maintains a water level over 1 m for several months [35]. At present the communication of the lagoons with the sea is very restricted, and mostly receive fresh water through channels that come from the river, which also collect the water used in rice fields. The most recent coastal lagoon is El Garxal, whose origin is due to the change in the mouth of the river from the great flood of the Ebro River in 1937 that caused the opening of a mouth in a northern direction, remaining that way until today.

Historical Evolution of the Ebro Delta

The delta of the Ebro River has gone through very different stages of development. The different features that the Ebro Delta has had since its inception are detailed in [24,36–38] among others. As with most of the deltas around the world margins, the onset of the Ebro Delta was related to the last maximum flooding by sea level reached at approximately 7000 years ago and the later retreating [24], and its evolution has been controlled by both natural and human-induced factors. The morphological evolution of the delta during the Holocene was the result of the successive accumulation of deltaic lobes at the mouth of the river, which advanced radially seawards from an avulsion point across the lowest lateral zones of the delta-plain [38]. During the 15th and 16th centuries the progradation of the delta increased due to intense deforestation in the Ebro drainage basin caused by changes in land use from forest to agricultural activities, military purposes during wars, and boat building for Spanish colonization of America [24]. Thus, from 1500 to 1650 the shoreline progradation rates increased by up to 50 m/yr at the river mouth and a delta plain were built up [39]. From the 17th to the 19th century, the shoreline progradation decreased (approximately 10 m/yr) caused by changes in the location of the river mouth [36]. The evolution of the Ebro Delta in the 20th century was associated with the construction of dams along the Ebro River, which entailed almost the suppression of river flooding over the delta plain and a drastic reduction of sediment feeding the mouth, especially since the dams of Flix (1948, with a reservoir capacity of 11 hm^3), Mequinenza (1966; 1534 hm^3) and Ribarroja (1969; 207 hm^3) were operated, all of them located in the lower course of the river [24]. The reduction of solid river discharge united with the subsidence of deltaic areas, which reach an average value of 3 mm [40], leading to increased erosion in almost all the deltaic coast except the two large spit bars, El Fangar and Los Alfaques. The area presenting the greatest retreat of the coastline is the Tortosa cape, located in the mouth of the river. The Trabucador bar also shows a marked coastline retreat; it has even fragmented on several occasions, the last January 2020 during the Gloria storm, and has not yet recovered (Figure 4). A distribution of erosion and sedimentation areas for the period 1957–2015 can be seen in [24].

Figure 2. Images of the hemidelta north and mouth. (**1**) El Fangar Spit; (**2**) Balsa de l'Estella or Estany del Canal Vell; (**3**) Riumar Beach, El Garxal Lagoon and San Antonio Island. (Source: General view: ESRI Co.; Photographs 1, 2 and 3: Guide of beaches of the Ministry for the Ecological Transition and the Demographic Challenge).

Figure 3. Images of the hemidelta south next to the mouth. (**1a**) Buda Island; (**1b**) Buda Island Break; (**2**) Migjorn mouth; (**3**) L'Alfacada Lagoon; (**4**) El Serrallo Beach and La Platjola Lagoon. (Source: General view: ESRI Co.; Photographs 1, 2 and 3: Guide of beaches of the Ministry for the Ecological Transition and the demographic challenge; Image (**1b**): Google Earth).

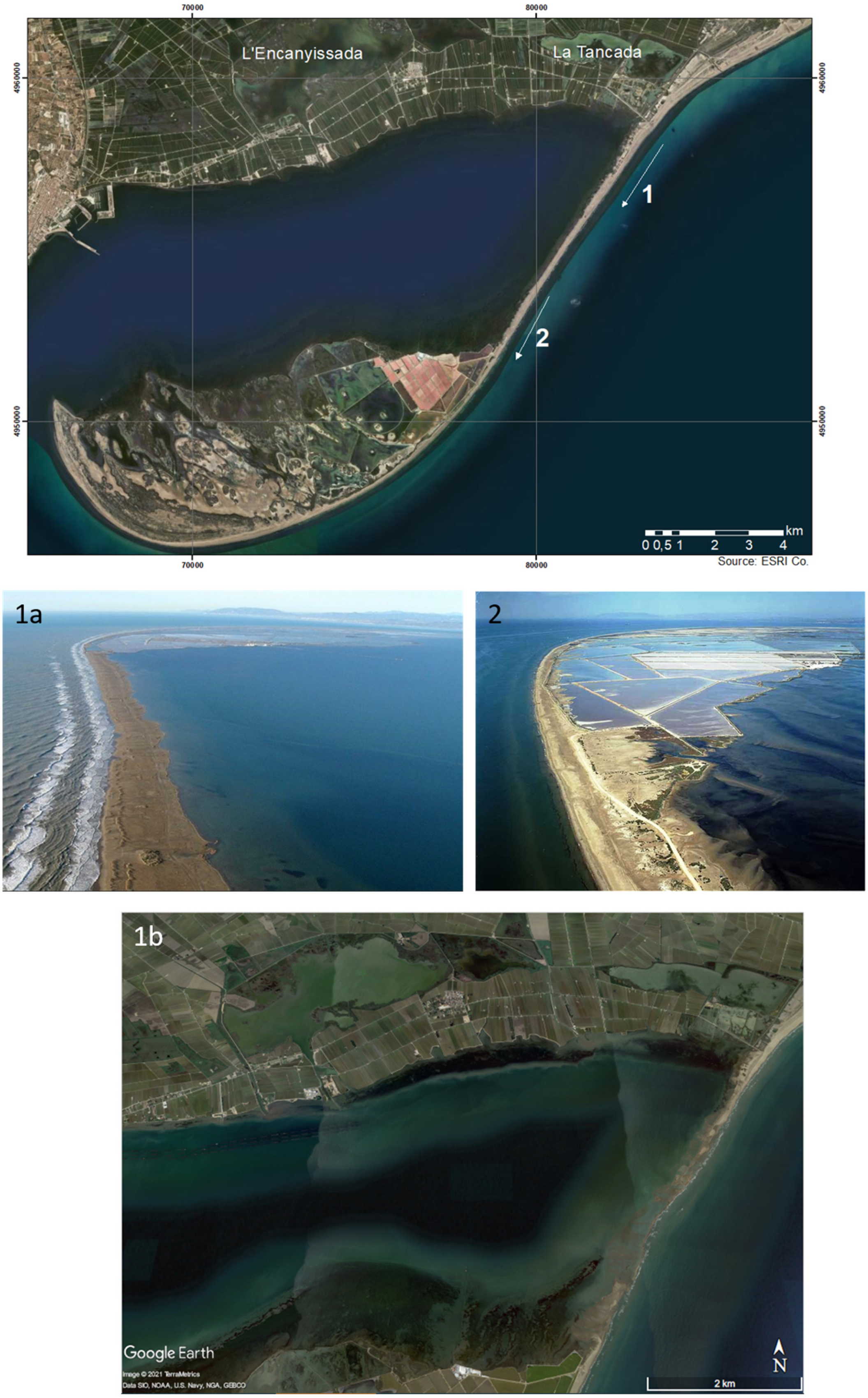

Figure 4. Images of the hemidelta south. (**1a**) Trabucador bar; (**1b**) Trabucador bar Break; (**2**); Trinitat saltworks and La Banya Spit. (Source: General view: ESRI Co.; Photographs 1a and 2: Guide of beaches of the Ministry for the Ecological Transition and the demographic challenge; Image (**1b**): Google Earth).

3. Main Threats to the Ebro Delta

The sustainability of coastal wetlands depends on the resilience of the geomorphic and ecological environments [41]. According to Cobani [42] sedimentation and/or coastal erosion are the main processes that must be controlled to guarantee the physical stability of coastal lagoons. The FAO document [43] collects the status of some Mediterranean coastal lagoon systems, and it is remarkable how most of them suffer the consequences of environmental changes linked to coastal erosion, subsidence, and meteorological events extremes recently amplified by global change.

Despite the protection figures that the Ebro Delta presents, there are several risks that threaten its littoral. The rising sea level, associated with global warming, represents one of them in the medium-long term, but there are other more immediate ones that threaten its stability, such as the lack of sediment inputs due to the regulation of the Ebro River (irrigation, reservoirs and hydroelectric power generation) causing the erosion and retreat of certain stretches of its coastline. Another threat to the Ebro Delta is the environmental degradation of the coastal lagoons, which are included within 25% of the natural habitats that are still conserved in the Ebro Delta [15].

3.1. Sedimentation Decrease

Among the factors that most affect the stability of the delta are the hydrological alterations caused by the reservoirs that imply important changes in the frequency and magnitude of the floods. The flooding provides the sediment to the delta that allows it to maintain or increase its thickness and its tendency to progradation and advance towards the sea, besides counteracting or balancing the sinking by the subsidence (soil compaction and tectonic subsidence) of the deltaic area [44]. The Ebro River is one of the Spanish rivers with the highest number of reservoirs in its basin, which is 97% regulated [45]. As has been indicated, the Mequinenza, Ribarroja and Flix reservoirs are mainly responsible for the modification of the hydrological characteristics of their lower course, since they retain practically 99% of the sediment transported by the river [46] causing a very negative effect in the Ebro Delta.

The low tidal range (20 cm) permit the existence of a salt wedge estuary in the deltaic reach, with a maximum saline intrusion of 32 km [44]. The dams interrupt the continuity of sediment transport modifying the transport capacity of solids, favouring the saline intrusion and reducing the thickness of the freshwater layer, preventing its use for agricultural operations. The effects of the saline wedge in the Ebro Delta have been studied in detail by Guillén and Palanques [47] and Movellán [48], among others.

3.2. Environmental Degradation of the Coastal Lagoons

The coastal lagoons of the Ebro Delta face a series of threats that are leading to a clear environmental deterioration. These threats can be summarised as follows: saline intrusion, agricultural activity and urban pressure [49]. All coastal lagoons are affected by the inundation of the deltaic shelf that can occur when storms meet the meteorological tide. This process will be aggravated by sea level rise due to climate change. This causes seawater and sediment to enter the lagoons. Coastal lagoons are also affected by rice fields, through alteration of the natural hydrological cycle as a result of freshwater inputs during the rice growing season (April to September [10]). In addition, despite all efforts to reduce the large amounts of nutrients and pesticides supplied for fertilization and care of the rice fields [50], problems related to eutrophication and pollution of wetlands continue to exist [49]. The degree of threat for each coastal lagoon varies, with the most threatened being the lagoons of Buda Island, l'Alfacada, Platjola, La Tancada and l'Encanyissada (Figures 1–4).

The Buda Island lagoon (Figure 3) is separated from the sea by a narrow dune barrier which, due to the lack of sediment from the river, is decreasing and producing a process of regression. This makes it more likely to break in strong storms (as happened with the Gloria storm in January 2020, Figure 3), allowing saline and sediment intrusion into the lagoon [51]. Sediment inflow is clogging the lagoon, which, together with regression, is causing a reduction in the lagoon's depth and surface area [16,52]. This coastal lagoon has also been affected by eutrophication processes caused by the drainage of rice crops. The El Garxal lagoon (Figure 2) is the only one not directly affected by irrigation surpluses from the rice fields of the Ebro Delta. The Platjola and Tancada lagoons (Figure 3) are affected by urban construction on the coast and the drains from the rice fields near the lagoons [16].

As indicated above, coastal lagoons are codified as priority habitats in the EU. The inclusion of the Ebro Delta in the Natura 2000 Network establishes as conservation objectives, among others, avoiding the reduction of the habitats of European interest under conservation [34]. The loss of surface area of the coastal lagoons due to the effect of regression and their environmental deterioration means that the conservation objectives established for these coastal lagoons will not be achieved [52].

3.3. Global Change

The geographically largest impacts on coastal wetlands will be caused by global climate change, and since rates of warming are generally expected to increase in the near future, projected climate change-related impacts are also expected to rise [53]. Climate change affects processes in many ways: by changing relative sea level; by increasing the frequency and intensity of storms; and by altering the temperature.

Coastal wetlands are very fragile systems, very sensitive to climate change, and any alteration that occur, both in the continental and marine environments, generates very negative effects on the entire system [54]. Global climate change is expected to accelerate the disappearance and degradation of many coastal wetlands, as well as the loss or decline of their species, and will harm the human populations dependent on their services [2]. As has been mentioned previously, the coastal wetlands are considered blue carbon ecosystems, and the alteration of these ecosystems can release to the atmosphere large amounts of previously sequestered carbon [55], contributing to global warming [56].

3.3.1. Sea Level Rise

The IPCC has identified "deltas, estuaries, and small islands" as the coastal systems most vulnerable to climate change and sea-level rise [53]. Climate change–related sea level rise will cause continued inundation of low-lying areas, especially where natural buffers have been removed [57]. The IPCC's Sixth Assessment Report [53] considers, in the worst possible scenario, a rise in sea level between 0.63–1.01 m in the year 2100, and a range of 0.98–1.88 m to 2150. These forecasts are aggravated in the Mediterranean area, as indicated in recent studies that estimate that warming in the Mediterranean basin occurs 20% faster than the average of the planet [58] or the forecast made by Kulp and Strauss [59] about the flooding of the Ebro Delta in 2050. In deltaic areas, to this are added the effects of subsidence, which in the case of the Ebro Delta is estimated to be almost 3 mm annually on average [40].

According to Sánchez-Arcilla et al. [13] relative sea-level rise will become the most important climate-induced potential hazard for the Ebro Delta because of its morphology, causing the inundation/flooding of low-lying areas below the rise in sea level. Figure 5 shows a simulation of the state in which the deltaic plane would be if a 75 cm rise occurred [28]. This model does not consider the gradual adaptation that the coast would make to the progressive changes driven by marine dynamic.

Another of the consequences of the sea level rise is a decrease of the return period of water levels associated with storm surges giving rise to a vertical displacement of the mean water level [13].

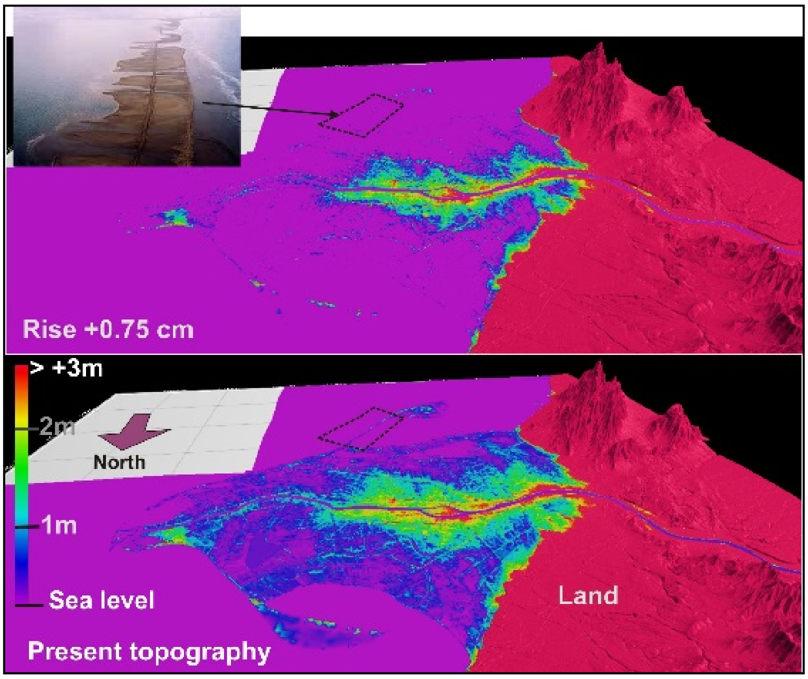

Figure 5. Modelling of the delta morphology with a rise in sea level of 0.75 m and with local subsidence [28].

3.3.2. Increase in the Frequency and Intensity of Storms

The increased stormy weather, together with the sea level rise, are considered as the main problems of climatic change in coastal zones [60]. Paleontological, geomorphological and sedimentological analyzes show an increasing trend in storms [61]. Oria [62] has analysed the statistical behaviour of the most extreme daily rainfalls recorded in the peninsular Mediterranean provinces from the 219 stations belonging to the network of main and secondary roads of AEMET, since 1965 to 2020. The trends found in precipitation distribution point to an increase in frequency and intensity of the situations that cause very heavy or torrential rains and of the significant extension in the whole of the Spanish Mediterranean.

For some years, progress has been made in the modeling of the Mediterranean hurricanes, so-called medicanes [63–67]. Medicanes are intense cyclones that acquire tropical characteristics, associated with extreme winds and rainfall [67]. The average frequency of only one to two events per year [64] but produces severe damage on coastal areas caused by extreme weather, strong winds and flooding, thus posing a serious natural hazard to populated areas along Mediterranean coasts. González-Aleman et al. [67] have investigated the response of the medicanes to global warming using a global climate model adapted to the present climate conditions, finding a decrease in frequency of medicanes at the end of the 21st century, but these become more hazardous, lasting longer and producing stronger winds and rainfall. This trend is consistent with the results of other previous models [64–66]. According to Sánchez-Arcilla et al. [13] an increase in stormy weather (frequency and/or intensity) induce a greater frequency and/or magnitude of erosive events since an increase in the annual average wave height induce an increase in the magnitude of the sediment transport rates along the coast and, normally, an increase in the magnitude of coastal changes. Since coastal recovery processes are slower than erosive ones, this increase should induce a greater erosive trend in the coastal behaviour and, in some cases, could induce a net erosive long-term trend level.

Since 2019, in the Mediterranean coast there have been some stormy evens (September and October 2019), Gloria storm (January 2020) and Filomena storm (January 2021), which have been particularly damaging in the Ebro Delta. In the case of the Gloria storm, since the instrumental record is available, never before has there been a storm with so much precipitation for three days in a row, and never before have there been three storms as intense as those of September and October 2019, besides Gloria [6]. The effects of the Gloria storm over the delta front were catastrophic [51], so that the next storm that occurred in the area on 27 and 28 November 2020, without being particularly intense, caused the Trabucador to break again and had a strong impact on the island of Buda [51].

3.3.3. Increase in Temperature

As already indicated, coastal lagoons are particularly vulnerable to global climate change. The predicted temperature increase could be 4.4 °C by 2100 [53], entailing important consequences on planktonic communities. Changes in the metabolism of planktonic communities [68,69], in the structure and function of planktonic food webs [70], as well as an increase in microplanktonic communities of smaller size and lower DNA content [71] have been observed with increasing water temperatures. Moreover, altering the temperature and salinity of coastal habitats would make them inhospitable to species with narrow temperature tolerance [72], could change the abundance and distribution of species as well as the functioning of ecosystems [58,73], and could affect species reproduction timing and migration patterns [74].

Warming can also exacerbate the problem of eutrophication, leading to algal overgrowth, fish kills and dead zones [75]. The next few decades will see large increases in rates of eutrophication and prevalence of hypoxic or dead zones as levels of nutrient inputs and wastes rise and as ocean waters warm [72]. Recent studies in the Mediterranean Sea indicate that climate change is already leading to an increased extinction risk for endemic fauna, a loss of habitat complexity and changes in ecosystem configurations [10,76–78]. Likewise, a 10-year study in western Mediterranean Sea revealed that climate-induced changes in water temperature and stratification produced an increase of small-sized phytoplankton (picoplankton and nanoflagellates) able to support regenerated production and a decline of diatoms, which are responsible for new production [79]. Moreover, warming, stratification and other physical properties appear to strongly impact the physiology and behaviour of harmful algae bloom species [80]. In Mediterranean coastal areas, more frequent harmful algal blooms (HABs), and new species have been recorded [80].

Although the invasion of new species is mainly linked to global flows, notably those associated with air and sea transport, climate change is expected to increase the risk of biological invasions [81], as global warming would remove the hostile climate constraint in the receiving area [82]. The increase in water temperature in the Mediterranean Sea would be a great advantage to tropical invasive species over native species [83]. In the Ebro Delta, 200 invasive nonindigenous species have already been quantified, with the apple snail (*Pomacea canaliculata*), zebra mussel (*Dreissena polymorpha*), red crab (*Procambarus clarkii*), blue crab (*Callinectes sapidus*), gambusia (*Gambusia holbrooki*), and bullfrog (*Lithobates catesbeianus*) having the greatest impact [16].

4. Strategies for Adaptation and Mitigation of Global Change in the Ebro Delta

The erosion problem of the Ebro Delta has been the subject of numerous studies and proposals for action to alleviate the problems that this entails [16,17,84]. Rodríguez-Santalla et al. [17] present several proposals that have been raised at different times, and some outstanding works already executed, which contemplate alternatives consisting of works of different magnitude, diversion of the mouth or use of those retained in the reservoirs. Others propose less impactful natural protection mechanisms with lower and more sustainable costs, in line with the current trend of environmental protection, such as the implantation of traps to retain sediment mobilized by wind or drift, or the beach drainage system. Other initiatives are aimed at restoring the flow of sediment through the river and the channels permanently from the reservoirs of the final section, with the aim of optimizing the processes of vertical accretion (soil formation) and decomposition of the organic matter in rice paddies and artificial wetlands [85].

Previous IPCC reports [86] contemplate three strategies to reduce the impact of climate change on coastal areas: setback, protection, and adaptation [87]. In the case of the Ebro Delta, the policies of action by the administration of the last decade have been oriented towards the withdrawal and incorporation of land into the public domain [88]. According to Pranzini et al. [89], the designation of the coast as a public domain by the Spanish Coastal Law in 1988, which includes set-back lines, regional responsibility of most issues of land planning and environmental protection, use of zoning as a conflict solution tool, constitute achievements in Spanish coastal management. Alvarado et al. [90] and Fatoric and Chelleric [11] propose the adaptation of the system to the new sea-level conditions. According to the IPCC [53], the best strategies for adaptation to the impact of climate change in coastal areas are the strengthening of dunes, the acquisition of land and the creation of marshes/wetlands as retarders of sea-level rise and floods, as well as protection of existing natural barriers. Ibañez et al. [85] propose the "rising grounds" (vertical accretion or aggradation) through the introduction of fluvial sediments into the delta plain, as the best adaptation strategy in most deltas for high-end scenarios of sea-level rise.

The Ministry for the Ecological Transition and the Demographic Challenge has recently presented the "Plan for the protection of the Ebro Delta" [16] in which it analyzes its current problems in order to guarantee its permanence and sustainability, and highlights among other problems, the lack of sediment inputs and the environmental status of the coastal lagoons. Also, it includes the most recent action measures oriented to mitigate the negative impact of climate change. The proposed actions can be summarized as: (1) to incorporate new lands into the public domain; (2) to establish a buffer zone that allows the free movement of the coast, taking into account the new horizons of rising sea level; (3) different sand bypassing from the areas where there exists coastal accretion to the erosive areas, recommending the following sand transfers: (a) from El Fangar spit to La Marquesa beach; (b) from Riumar and the coastal front of El Garxal to Tortosa cape and Sant Antonio Island; (c) from Eucaliptus beach to Tortosa cape and Sant Antonio Island; (d) from La Banya spit to the El Trabucador beach. The principles of action of this Ebro Delta Protection Plan is to avoid rigid coastal defences, but in the case of the sand bypassing consideration should be given to studies to assess the need and optimize the design of various elements of control and retention of sand before entering the sinkholes (bays), at the tip of the Fangar and the tip of the Banya. The two first proposals of this plan are related to effective coastal management, but the third proposal requires carefully assessing the trade-offs between environmental impacts and infrastructures performance [87], especially in an area of high ecological and environmental value such as the delta of the Ebro River. According to the principles of ecological engineering, the restoration of deltaic systems must be based on a deep knowledge of the functioning of these systems, allowing them to evolve according to their natural forces, and adapting land uses (and economic activities) to geomorphic ecology [85]. In 2020, the Catalan Government approved Law 8/2020, on the Protection and Management of the Coastline of Catalonia [91]. It is oriented towards the abandonment of general regulations considering territorial diversity, guaranteeing the preservation of the integrity of coastal ecosystems, as well as landscapes and coastal geomorphology, and preventing and reducing the effects of natural hazards, in particular those of the climatic emergency, which may be caused by natural or human activities. Therefore, any initiative taken must pass through the filter of this law.

5. Discussion

As has been seen, the coastal areas, and especially the coastal wetlands, are under severe threat that puts their stability at risk. The delta ecosystems and the services it provides (storm protection, nutrient and pollution removal, maintenance of biodiversity, carbon storage, etc.) are being destroyed [92,93]. In this work, a review has been made of the threats that affect the integrity of the deltaic system, as well as the actions that have been planned and/or carried out, most of them with rather limited success. According to Loucks [93], while many deltas suffer from similar problems, the solutions most appropriate for each delta are specific and unique, because every delta has is its own biophysical aspects; dominant economic activities; population densities; culture and social life; land-use patterns; agriculture, environmental, industrial and urban forms and networks and issues; governance structures; and financial means.

The Ebro Delta has been strongly modified by human management (rice fields monoculture and dams construction). Conversion to other land uses is the primary direct driver of the loss and degradation of coastal wetlands [2]. European deltas are facing increasing pressure from human activities that exploit their natural resources in order to achieve economic development [94]. The Po Delta was also transformed by fishing (salt marshes were transformed into fishing lagoons by bringing in seawater through artificial canals), aquaculture and tourism (main factor that has transformed the beaches of the delta) [94]. The Ebro Delta presents a deficit of sediment mainly caused by the presence of large dams that retain it and prevent vertical accretion from taking place, which, together with the effects of the subsidence of the terrain, contribute to the reduction of elevation and, therefore, favouring the flooding. To maintain the vertical elevation of wetland through preserving the natural river discharges [85] appears to be the most appropriate alternative. Natural areas of the Ebro Delta (mainly coastal lagoons) are being affected by regression and their environmental degradation. According to Giosan [92] and Ibáñez et al. [85], the restoration of coastal wetlands is one of the most successful measures to combat flooding due to sea level rise and can compensate somewhat for lack of sediment. Therefore, it is crucial to control the factors that are affecting the degradation of these coastal lagoons, mainly the excessive nutrient loading associated with the use of nitrogen and phosphorus in fertilizers, urban pressure and saltwater intrusion. Some studies of wetland restoration in abandoned rice fields carried out in the Ebro Delta achieved a reduction in nutrient levels in water draining from rice fields, an improvement of habitats for protected bird species, and an increase in spatial heterogeneity and diversity of the landscape [95,96].

As with the Ebro Delta, most of the Mediterranean deltas have been impacted by human activities. According Loucks [93] the feasible options available for protection depend largely on the particular delta and the funding available. However, the solutions proposed to reduce erosion in the Ebro Delta should consider those taken in other Mediterranean deltas, and their effects on the coast. Day et al. [97] analyzed the vertical accretion and surface elevation change in four European coastal systems (the Ebro Delta, Spain; the Rhône Delta, France; and the Po Delta and Venice Lagoon, Italy) showing that the rates of vertical accretion and surface elevation gain were generally much higher at riverine sites where the river still has some influence. In the case of the Ebro Delta (and Rhône Delta), the high salinity of the soil results in the inability of sufficient plant production to offset elevation loss [97]. The Nile Delta presents a similar situation to that of the Ebro Delta, the reduced sediment supply due to upstream dams is the main cause of the subsidence and its erosive problems. About 60% of the Nile Delta coast is partially stabilized by engineering structures and sand dunes (17.5 and 42.5%, respectively), while the remaining coast (40%) is not protected [98]. According to El Sayed and Khalifa [99], these hard structures (seawalls, detached breakwaters, groins, and harbor/estuary entrance jetties) have side effects as they cause erosion and accretion in the down and updrift, respectively, and also they may create weak circulation causing water stagnation which will affect the water quality badly. In the case of the delta of the Po River, some zones are below sea level due to the high subsidence as a result of methane extraction and kept dry by artificial banks, levees and pumps [92]. The Danube Delta, declared a Biosphere Reserve by UNESCO (1991), remains one of the best preserved deltas in Europe [100]. In 2007, the EU-FP6 CONSCIENCE project was launched with a view to enhancing the implementation of a scientifically based sustainable coastal erosion management in Europe, testing scientific concepts and tools in six pilot sites around Europe, among them the Danube Delta (http://www.conscience-eu.net/ accessed on 12 October 2021). In this way, new concepts of coastal dynamics, such as coastal sediment circulations cells along the Danube Delta coast, have been developed in order to increase insight into coastal erosion processes and contribute to finding adaptive solutions [101].

To the effects caused by human action, those caused by natural phenomena are added, which are accentuated by global change. One of the greatest threats to coastal wetlands is the variation in sea level. As already explained, the sedimentary deficit of the Ebro Delta joined to the subsidence increase their vulnerability to flooding both in terms of extent and duration [93]. According Nicholls et al. [102] sea-level rise over the last century has reduced the return period of extreme water levels, exacerbating the damage to fixed structures from modern storms compared to the same events a century ago. Another global change-induced effect is the increase in water temperature, which is already causing changes in species composition and abundance in the Mediterranean [10]. In the Western Mediterranean, climate change influences the boundaries of biogeographic regions, with some warm water species extending their ranges and colonising new regions where they were previously absent [103]. The environmental, economic and social impact of invasive species on deltas can be drastic, and even those that appear to be minor in the short term can have serious consequences over time [82]. European deltas are already facing the problem of invasive species, such as the Ebro Delta [16], Nile Delta [104] and Danube Delta [105], and this is expected to be intensified by rising temperatures. To predict the consequences of climate change for delta environments, it is necessary to measure parameters that are indicative of underlying mechanisms of climate-induced changes, and the maintenance of sustained monitoring (large-scale and long-term programmes and local efforts) [103]. Further research is needed to predict when and under what conditions climate-induced regime shifts of delta ecosystems will occur, if such changes will be reversible, and if so, what the recovery dynamics would be [103].

On the other hand, Constanza et al. [106] quantified losses due to changes in tidal marshes and mangroves in the US (which amounted to 7.2 trillion dollars) to help influence political decisions taking into account the true value of nature. The Mediterranean Wetlands Observatory [107] compared between 1990 and 2005 the loss of natural wetland habitats between 35 sites that were on the Ramsar list and the 132 that were not concluding that "the mere inclusion of a site in the Ramsar list does not guarantee the conservation of the natural wetland habitats it contains". For its part, the Ministry of Agriculture, Food and the Environment of Spain financed the Millennium Ecosystem Assessment of Spain, concluding that 45% of the ecosystem services evaluated have been degraded or are being used unsustainably, the coastal wetlands and continental ones being those that have suffered a greater deterioration in their flow of services and, therefore, in their ability to contribute to the well-being of the population [108]. According to Agardy and Alder [72], it is paradoxical that despite the value of coastal areas in supporting tourism, it is the tourism industry itself that degrades these areas with waste.

Pranzini et al. [89] make an exhaustive review of the major management aspects of coastal erosion and defence in Europe and discusses the large spectrum of shore protection strategies used. They propose that a much broader cooperation that crosses boundaries between the developed/developing worlds' needs to be put into practice and consider a joint decision-making arrangement between coast to watershed. This is especially important for rivers such as the Danube that flow through multiple countries and where the negotiations on sediment rights, like those on water allocations, can be complex [93]. On the other hand, the different national and international frameworks for environmental conservation provide the legal instruments to administer the management and protection of a delta's natural and human resources.

In addition, involvement of stakeholders and citizens helps generate societal support for management or policy decisions [93]. Romagosa and Pons [109] analyzed the perception of the effects of, and vulnerability to, climate change in the Ebro Delta of the representative stakeholders (economic sectors, environmental and territorial managers, political decision-makers, etc.) by means of surveys. The result shown that the effects of the climate change on the delta itself and its economic activities have been widely accepted, and also that not enough effort is being made to face this problem. Therefore, it is necessary to establish more effective communication among all agents concerned encourage the discussion about the best strategies that take into account he interests of the majority. According to Loucks [93], public education is a major component of successful stakeholder involvement, and thus the affected governments should make efforts to contribute to knowledge and develop a science-based global strategy for protecting deltas to reduce costs and risks [92].

6. Conclusions

Most of the coastal wetlands are altered by both human activity and natural processes. The largest coastal wetlands in the Mediterranean are found in deltaic areas. This work has shown the role of deltas on the coast, as well as the threats and the different solutions towards avoiding coastal erosion. As has already been seen, variations in sea level, caused by climate change, represent the greatest threat to coastal wetlands, mainly because of loss of vertical accretion of the delta plain due to sediment retention in the dams, increasing the negative effects of subsidence. All of this generates a global imbalance over the entire delta, initiating a process of progressive retreat of the coast that can lead to its complete disappearance. Therefore, governments should accelerate scientific research and expand monitoring and forecasting programmes, impact studies and public consultations to prevent their disappearance.

Author Contributions: All authors contributed equally to this work. All authors have read and agreed to the published version of the manuscript.

Funding: This work was funded by the Universidad Rey Juan Carlos (Spain), under the project "Análisis biogeomorfológico del sistema barrera-laguna costera del delta del Ebro. Estudio de su función como ecosistema centinela del cambio global (LAGUNERO)".

Conflicts of Interest: The authors declare no conflict of interest.

References

1. *Convention on Wetlands of International Importance especially as Waterfowl Habitat*; United Nations Educational, Scientific and Cultural Organization (UNESCO): Ramsar, Iran, 1971.
2. Millennium Ecosystem Assessment. *Ecosystems and Human Well-Being: Wetlands and Water Synthesis*; World Resources Institute: Washington, DC, USA, 2005.
3. Santos, R.; Silva, J.; Alexandre, A.; Navarro, N.; Barrón, C.; Duarte, C.M. Ecosystem metabolism and carbon fluxes of a tidally-dominated coastal lagoon. *Estuaries* **2004**, *27*, 977–985. [CrossRef]
4. Barbier, E.B.; Hacker, S.D.; Kennedy, C.; Koch, E.W.; Stier, A.C.; Silliman, B.R. The value of estuarine and coastal ecosystem services. *Ecol. Monogr.* **2011**, *81*, 169–193. [CrossRef]
5. Duarte, C.M.; Losada, I.J.; Hendriks, I.E.; Mazarrasa, I.; Marbà, N. The role of coastal plant communities for climate change mitigation and adaptation. *Nat. Clim. Chang.* **2013**, *3*, 961–968. [CrossRef]
6. McLeod, E.; Chmura, G.L.; Bouillon, S.; Salm, R.; Björk, M.; Duarte, C.M.; Lovelock, C.E.; Schlesinger, W.H.; Silliman, B.R. A blueprint for blue carbon: Toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2. *Front. Ecol. Environ.* **2011**, *9*, 552–560. [CrossRef]
7. Nelleman, C.; Corcoran, E.; Duarte, C.M.; Valdes, L.; DeYoung, C.; Fonseca, L.; Grimsditch, G. *Blue Carbon: The Role of Healthy Oceans in Binding Carbon*; UNEP/FAO/UNESCO/IUCN/CSIC: Birkeland, Norway, 2009.
8. Williams, M. Conservation: Wetlands. In *International Encyclopedia of the Social & Behavioral Sciences*; Smelser, N.J., Baltes, P.B., Eds.; Elsevier: Pergamon, Germany, 2001; pp. 2621–2624. [CrossRef]
9. Mójica-Vélez, J.M.; Barrasa-García, S.; Espinoza-Tenorio, A. Policies in coastal wetlands: Key challenges. *Environ. Sci. Policy* **2018**, *88*, 72–82. [CrossRef]
10. MedECC. *Climate and Environmental Change in the Mediterranean Basin—Current Situation and Risks for the Future*; Union for the Mediterranean, Plan Bleu, UNEP/MAP: Marseille, France, 2020; p. 632.
11. Fatorić, S.; Chelleri, L. Vulnerability to the effects of climate change and adaptation: The case of the Spanish Ebro Delta. *Ocean Coast. Manag.* **2012**, *60*, 1–10. [CrossRef]
12. Nicholls, R.J.; Hoozemansb, F.M.J. The Mediterranean: Vulnerability to coastal implications of climate change. *Ocean Coast. Manag.* **1996**, *31*, 105–132. [CrossRef]
13. Sánchez-Arcilla, A.; Jiménez, J.A.; Valdemoro, H.I.; Gracia, V. Implications of Climatic Change on Spanish Mediterranean Low-Lying Coasts: The Ebro Delta Case. *J. Coast. Res.* **2008**, *242*, 306–316. [CrossRef]

14. Day, J.W.; Ibáñez, C.; Pont, D.; Scarton, F. Chapter 14—Status and Sustainability of Mediterranean Deltas: The Case of the Ebro, Rhône, and Po Deltas and Venice Lagoon. In *Coasts and Estuaries*; Wolanski, E., Day, J., Elliott, M., Ramachandran, R., Eds.; Elsevier: Berkeley, CA, USA, 2019; pp. 237–249.
15. Cardoch, L.; Day, J.W.; Ibañez, C. Net primary productivity as an indicator of sustainability in the Ebro and Mississippi deltas. *Ecol. Appl.* **2002**, *12*, 1044–1055. [CrossRef]
16. CEDEX. Plan para la Protección del Delta del Ebro. Centro de Estudios de Puertos y Costas. In *Ministerio Para la Transición Ecológica y el Reto Demográfico. Secretaría de Estado de Medio Ambiente. Dirección General de Sostenibilidad de la Costa y del Mar*; CEDEX: Madrid, Spain, 2021.
17. Rodríguez-Santalla, I.; Serra, J.; Montoya, I.; Sánchez-García, M.J. El delta del Ebro Características dinámicas y ambientales y propuestas para su protección. In *El litoral Tarraconense*; Rodríguez-Santalla, I., Montoya, I., Sánchez, M.J., Eds.; JMC Ofimática S.L: Barcelona, Spain, 2011.
18. Rodríguez, I. *Evolución Geomorfológica del Delta del Ebro y Prognosis de su Evolución*; Universidad de Alcalá de Henares: Madrid, Spain, 1999.
19. Sierra, J.P.; Sánchez-Arcilla, A.; Figueras, P.A.; Río, J.G.D.; Rassmussen, E.K.; Mösso, C. Effects of discharge reductions on salt wedge dynamics of the Ebro River. *River Res. Appl.* **2004**, *20*, 61–77. [CrossRef]
20. Tena, A.; Vericat, D.; Batalla, R.J. Balance sedimentario del embalse de Ribarroja. *Cuad. Investig. Geográfica* **2021**, *47*, 415–433. [CrossRef]
21. Vericat, D.; Batalla, R.J. Sediment transport in a large impounded river: The lower Ebro, NE Iberian Peninsula. *Geomorphology* **2006**, *79*, 72–92. [CrossRef]
22. Sánchez-García, M.J.; Montoya-Montes, I.; Casamayor, M.; Alonso, I.; Rodríguez-Santalla, I. Coastal dunes in the Ebro Delta. In *The Spanish Coastal Systems*; Springer: Berlin/Heidelberg, Germany, 2019; pp. 611–630.
23. Sanchez-Arcilla, A.; Gonzalez-Marco, D.; Bolaños, R. A review of wave climate and prediction along the Spanish Mediterranean coast. *Nat. Hazards Earth Syst. Sci* **2008**, *8*, 1217–1228. [CrossRef]
24. Rodríguez-Santalla, I.; Somoza, L. The Ebro river delta. In *The Spanish Coastal Systems*; Springer: Berlin/Heidelberg, Germany, 2019; pp. 467–488.
25. Maldonado, A. Sedimentation, stratigraphy, and development of the Ebro Delta, Spain. In *Delta Models for Exploration*; Broussard, M.L., Ed.; Houston Geological Society: Houston, TX, USA, 1975; pp. 311–338.
26. Jiménez-Quintana, J.A. *Evolución Costera en el Delta del Ebro. Un Proceso a Diferentes Escalas de Tiempo y Espacio*; Universidad Politécnica de Cataluña: Barcelona, Spain, 1996.
27. Serra, J. El sistema sedimentario del Delta del Ebro. *Rev. Obras Públicas* **1997**, *3*, 15–22.
28. Somoza, L.; Rodríguez-Santalla, I. Geology and geomorphological evolution of the Ebro River Delta. In *Landscapes and Landforms of Spain, World Geomorphological Landscapes*; Gutiérrez, F., Gutierrez, M., Eds.; Springer: Berlin/Heidelberg, Germany, 2014; pp. 213–227.
29. Rodríguez-Santalla, I.; Sánchez-García, D.G.; Montoya-Montes, I.; Martín, T.; Martín-Velázquez, S.; Parra, M.J.B.; Serra, F.J.; Gracia, F.J. Comparación de la dinámica dunar entre las formaciones situadas en los hemideltas norte y sur del río Ebro. *Geotemas* **2017**, *17*, 287–290.
30. Rodríguez-Santalla, I.; Sánchez-García, M.J.; Montoya-Montes, I.; Gómez-Ortiz, D.; Martín-Crespo, T.; Serra-Raventós, J. Internal structure of the aeolian sand dunes of El Fangar spit, Ebro Delta (Tarragona, Spain). *Geomorphology* **2009**, *104*, 238–252. [CrossRef]
31. Rodríguez-Santalla, I.; Díez-Martínez, A.; Navarro, N. Vulnerability Analysis of the Riumar Dune Field in El Garxal Coastal Wetland (Ebro Delta, Spain). *J. Mar. Sci. Eng.* **2021**, *9*, 601. [CrossRef]
32. Rodríguez-Santalla, I.; Gomez-Ortiz, D.; Martín-Crespo, T.; Sánchez-García, M.J.; Montoya-Montes, I.; Martín-Velázquez, S.; Barrio, F.; Serra, J.; Ramírez-Cuesta, J.M.; Gracia, F.J. Study and Evolution of the Dune Field of La Banya Spit in Ebro Delta (Spain) Using LiDAR Data and GPR. *Remote Sens.* **2021**, *13*, 802. [CrossRef]
33. Soria, J.M.; Sahuquillo, M. *Lagunas Costeras*; Ministerio de Medio Ambiente, y Medio Rural y Marino: Madrid, Spain, 2009.
34. Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. *Off. J. Eur. Communities* **1992**, *206*, 7–50.
35. Comin, F.A. Características físicas y químicas y fitoplancton de las lagunas costeras, Encañizada, Tancada y Buda (Delta del Ebro). *Oecologia Aquat.* **1984**, *7*, 79–162.
36. Maldonado, A. *El Delta del Ebro: Estudio Sedimentológico y Estratigráfico*; Boletín de Estratigrafía: Barcelona, Spain, 1972.
37. Cearreta, A.; Benito, X.; Ibáñez, C.; Trobajo, R.; Giosan, L. Holocene palaeoenvironmental evolution of the Ebro Delta (Western Mediterranean Sea): Evidence for an early construction based on the benthic foraminiferal record. *Holocene* **2016**, *26*, 1438–1456. [CrossRef]
38. Somoza, L.; Barnolas, A.; Arasa, A.; Maestro, A.; Rees, J.G.; Hernandez-Molina, F.J. Architectural stacking patterns of the Ebro delta controlled by Holocene high-frequency eustatic fluctuations, delta-lobe switching and subsidence processes. *Sediment. Geol.* **1998**, *117*, 11–32.
39. Palanques, A.; Guillén, J. Coastal changes in the Ebro delta: Natural and human factors. *J. Coast. Conserv.* **1998**, *4*, 17–26.
40. Martínez-Eixarch, M.; Rovira, A.; Trobajo, R.; Caiola, N.; Jornet, L.; Ibáñez, C. Medidas de adaptación y mitigación al cambio climático en el Delta del Ebro: Proyecto life ebro—Admiclim. *Agric. Vergel* **2015**, *383*, 153–155.

41. Reed, D.; van Wesenbeeck, B.; Herman, P.M.J.; Meselhe, E. Tidal flat-wetland systems as flood defenses: Understanding biogeomorphic controls. *Estuar. Coast. Shelf Sci.* **2018**, *213*, 269–282. [CrossRef]
42. Cobani, M. Albania. In *Mediterranean Coastal Lagoons: Sustainable Management and Interactions among Aquaculture, Capture Fisheries and the Environment*; Cataudella, S., Crosetti, D., Massa, F., Eds.; FAO Studies and Reviews: Rome, Italy, 2015; Volume 95, pp. 51–89.
43. FAO. *Mediterranean Coastal Lagoons: Sustainable Management and Interactions among Aquaculture, Capture Fisheries and the Environment*; Cataudella, S., Crosetti, D., Massa, F., Eds.; FAO Studies and Reviews: Rome, Italy, 2015; pp. 29–35.
44. Ibañez, C.; Prat, N.; Canicio, A. Changes in the hydrology and sediment Transport produced by large dams on the lower Ebro River and its estuary. *Regul. Rivers Res. Manag.* **1996**, *12*, 51–62. [CrossRef]
45. Batalla, R.J.; Vericat, D.; Tena, A. The fluvial geomorphology of the lower Ebro (2002–2013): Bridging gaps between management and research. *Cuad. Investig. Geográfica* **2014**, *40*, 29–52. [CrossRef]
46. Dolz, J.; Gomez, M.; Nieto, J. El Ebro en el delta. *Rev. Obras Públicas* **1997**, *3368*, 7–14.
47. Guillen, J.; Palanques, A. Sediment dynamics and hydrodynamics in the lower course of a river highly regulated by dams: The Ebro River. *Sedimentology* **1992**, *39*, 567–579. [CrossRef]
48. Movellán, E. *Modelado de la Cuña Salina y del Flujo de Nutrientes en el Tramo Estuarino del río Ebro*; Universitat de Barcelona: Barcelona, Spain, 2004.
49. Day, J.W.; Maltby, E.; Ibáñez, C. River basin management and delta sustainability: A commentary on the Ebro Delta and the Spanish National Hydrological Plan. *Ecol. Eng.* **2006**, *26*, 85–99. [CrossRef]
50. Martínez-Eixarch, M.; Curcó, A.; Ibáñez, C. Effects of agri-environmental and organic rice farming on yield and macrophyte community in Mediterranean paddy fields. *Paddy Water Environ.* **2016**, *15*, 457–468. [CrossRef]
51. Guillén, J. Impacto sobre la franja litoral. Vulnerabilidad en la costa catalana: Ejemplos de dinámica litoral. In *Resumen Sobre la Formación y Consecuencias de la Borrasca Gloria (19–24 enero 2020)*; Berdalet, E., Marrasé, C., Pelegrí, J.L., Eds.; Instituto de CC del Mar: Barcelona, Spain, 2020; pp. 3–4.
52. *Observaciones y Recomendaciones en Relacion al "Plan de Proteccion del Delta del Ebro"*; Generalitat de Catalunya, Departament D'agricultura, Ramaderia, Pesca I Alimentació: Barcelona, Spain, 2021.
53. IPCC. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I., et al., Eds.; Cambridge University Press: Cambridge, UK, 2021; in press.
54. Day, J.W.; Christian, R.R.; Boesch, D.M.; Yáñez-Arancibia, A.; Morris, J.; Twilley, R.R.; Naylor, L.; Schaffner, L.; Stevenson, C. Consequences of Climate Change on the Ecogeomorphology of Coastal Wetlands. *Estuaries Coasts* **2008**, *31*, 477–491. [CrossRef]
55. Pendleton, L.; Donato, D.C.; Murray, B.C.; Crooks, S.; Jenkins, W.A.; Sifleet, S.; Craft, C.; Fourqurean, J.W.; Kauffman, J.B.; Marba, N.; et al. Estimating global "blue carbon" emissions from conversion and degradation of vegetated coastal ecosystems. *PLoS ONE* **2012**, *7*, e43542. [CrossRef] [PubMed]
56. Lovelock, C.E.; Atwood, T.; Baldock, J.; Duarte, C.M.; Hickey, S.; Lavery, P.S.; Masque, P.; Macreadie, P.I.; Ricart, A.M.; Serrano, O.; et al. Assessing the risk of carbon dioxide emissions from blue carbon ecosystems. *Front. Ecol. Environ.* **2017**, *15*, 257–265. [CrossRef]
57. Church, J.A.; Gregory, J.M.; Huybrechts, P.; Kuhn, M.; Lambeck, C.; Nhuan, M.T.; Qin, D.; Woodworth, P.L. Changes in sea level. In *Climate Change 2001: The Scientific Basis: Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*; Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Dai, X., Maskell, K., Johnson, C.A., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2001; pp. 639–694.
58. Cramer, W.; Guiot, J.; Fader, M.; Garrabou, J.; Gattuso, J.-P.; Iglesias, A.; Lange, M.A.; Lionello, P.; Llasat, M.C.; Paz, S.; et al. Climate change and interconnected risks to sustainable development in the Mediterranean. *Nat. Clim. Chang.* **2018**, *8*, 972–980. [CrossRef]
59. Kulp, S.A.; Strauss, B.H. New elevation data triple estimates of global vulnerability to sea-level rise and coastal flooding. *Nat. Commun.* **2019**, *10*, 4844. [CrossRef]
60. Cendrero, A.; Sánchez-Arcilla, A.; Zazo, C.; Bardají, T.; Dabrio, C.J.; Goy, J.L.; Jiménez, J.A.; Mösso, C.; Rivas, V.; Salas, L.; et al. Impactos sobre las zonas costeras. In *Evaluación Preliminar de los Impactos en España por Efecto del Cambio Climático*; Moreno, J.M., Ed.; Ministerio de Medio Ambiente: Madrid, Spain, 2005.
61. Bardají, T.; Zazo, C.; Goy, J.L.; Dabrio, C.J.; Lario, J. Increase in storminess at the end of the Last Interglacial. Is it happening again? In Proceedings of the X Congreso Geológico de España, Vitoria-Gasteiz, Spain, 5–7 July 2021.
62. Oria, P. ¿Está Aumentando la Frecuencia o la Intensidad de las Precipitaciones Extremas en el Mediterráneo? Available online: https://aemetblog.es/2021/05/02/esta-aumentando-la-frecuencia-o-la-intensidad-de-las-precipitaciones-extremas-en-el-mediterraneo/ (accessed on 20 August 2021).
63. Gaertner, M.A.; Jacob, D.; Gil, V.; Domínguez, M.; Padorno, E.; Sánchez, E.; Castro, M. Tropical cyclones over the Mediterranean Sea in climate change simulations. *Geophys. Res. Lett.* **2007**, *34*, 2–5. [CrossRef]
64. Romero, R.; Emanuel, K. Medicane risk in a changing climate. *J. Geophys. Res. Atmos.* **2013**, *118*, 5992–6001. [CrossRef]
65. Cavicchia, L.; von Storch, H.; Gualdi, S. A long-term climatology of medicanes. *Clim. Dyn.* **2013**, *43*, 1183–1195. [CrossRef]
66. Tous, M.; Zappa, G.; Romero, R.; Shaffrey, L.; Vidale, P.L. Projected changes in medicanes in the HadGEM3 N512 high-resolution global climate model. *Clim. Dyn.* **2015**, *47*, 1913–1924. [CrossRef]

67. 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. *Geophys. Res. Lett.* **2019**, *46*, 1754–1764. [CrossRef]
68. García-Corral, L.; Barber, E.; Sal, S.; Holding, J.; Agustí, S.; Navarro, N.; Serret, P.; Mozetič, P.; Duarte, C.M. Temperature-dependence of planktonic metabolism in the Subtropical North Atlantic Ocean. *Biogeosciences* **2014**, *11*, 4529–4540. [CrossRef]
69. García-Corral, L.; Holding, J.; Carrillo, P.; Steckbauer, A.; Navarro, N.; Serret, P.; Gasol, J.M.; Morán, X.; Estrada, M.; Fraile-Nuez, E.; et al. Temperature dependence of plankton community metabolism in the subtropical and tropical ocean. *Glob. Biogeochem. Cycles* **2017**, *31*, 1141–1154. [CrossRef]
70. Vidussi, F.; Mostajir, B.; Fouilland, E.; Le Floc'h, E.; Nouguier, J.; Roques, C. Effects of experimental warming and increased ultraviolet B radiation on the Mediterranean plankton food web. *Limnol. Oceanogr.* **2011**, *56*, 206–218. [CrossRef]
71. Sommer, U.; Paul, C.; Moustaka-Gouni, M. Warming and Ocean Acidification Effects on Phytoplankton-From Species Shifts to Size Shifts within Species in a Mesocosm Experiment. *PLoS ONE* **2015**, *10*, e0125239. [CrossRef]
72. Agardy, T.; Alder, J. Coastal Systems (Chapter 19). In *Ecosystems and Human Well-Being: Current State and Trends*; Assessment, M.E., Ed.; Island Press: Washington, DC, USA, 2005.
73. Givan, O.; Edelist, D.; Sonin, O.; Belmaker, J. Thermal affinity as the dominant factor changing Mediterranean fish abundances. *Glob. Chang. Biol.* **2017**, *24*, e80–e89. [CrossRef]
74. Otero, J.; L'Abée-Lund, J.H.; Castro-Santos, T.; Leonardsson, K.; Storvik, G.O. Basin-scale phenology and effects of climate variability on global timing of initial seaward migration of Atlantic salmon (*Salmo salar*). *Glob. Chang. Biol.* **2013**, *20*, 61–75. [CrossRef]
75. WRI. *People and Ecosystems: The Fraying Web of Life*; World Resources Institute: Washington, DC, USA, 2000.
76. Azzurro, E.; Sbragaglia, V.; Cerri, J.; Bariche, M.; Bolognini, L. Climate change, biological invasions, and the shifting distribution of Mediterranean fishes: A large-scale survey based on local ecological knowledge. *Glob. Chang. Biol.* **2019**, *25*, 2779–2792. [CrossRef]
77. Montero-Serra, I.; Garrabou, J.; Doak, D.F.; Ledoux, J.; Linares, C. Marine protected areas enhance structural complexity but do not buffer the consequences of ocean warming for an overexploited precious coral. *J. Appl. Ecol.* **2019**, *56*, 1063–1074. [CrossRef]
78. Lasram, F.B.R.; Guilhaumon, F.; Albouy, C.; Somot, S.; Thuiller, W.; Mouillot, D. The Mediterranean Sea as a "culde-sac" for endemic fishes facing climate change. *Glob. Chang. Biol.* **2010**, *16*, 3233–3245. [CrossRef]
79. Marty, J.-C.; Chiavérini, J.; Pizay, M.-D.; Avril, B. Seasonal and interannual dynamics of nutrients and phytoplankton pigments in the western Mediterranean Sea at the DYFAMED time-series station (1991–1999). *Deep Sea Res. Part II Top. Stud. Oceanogr.* **2002**, *49*, 1965–1985. [CrossRef]
80. Legrand, C.; Casotti, R. Climate-induced changes and Harmful Algal Blooms in the Mediterranean: Perspectives on future scenarios. In *Phytoplankton Response to Mediterranean Environmental Change*; CIESM: Tunis, Tunisia, 2009; pp. 63–66.
81. Capdevila-Argüelles, L.; Zilletti, B.; Álvarez, V.A.S. Cambio climático y especies exóticas invasoras en España. In *Diagnóstico Preliminar y Bases de Conocimiento Sobre Impacto y Vulnerabilidad*; Oficina Española de Cambio Climático, Ministerio de Medio Ambiente y Medio Rural y Marino: Madrid, Spain, 2011; p. 146.
82. Stachowicz, J.J.; Terwin, J.R.; Whitlatch, R.B.; Osman, R.W. *Linking Climate Change and Biological Invasions: Ocean Warming Facilitates Nonindigenous Species Invasions*; Berenbaum, M.R., Ed.; University of Illinois at Urbana–Champaign: Urbana, IL, USA, 2002; pp. 15497–15500.
83. Galil, B.S.; Zenetos, A. A sea of change: Exotics in the eastern Mediterranean sea. In *Invasive Aquatic Species of Europe: Distribution, Impacts and Management*; Leppäkoski, E., Gollasch, S., Olenin, S., Eds.; Kluwer Academic Publishers: Dordrecht, The Netherlands, 2002; pp. 325–336.
84. Rodríguez, I. Shoreline Management Guide. Case Studies Ebro Delta (Spain). 2003. Available online: http://copranet.projects.eucc-d.de/files/000155_EUROSION_Ebro_delta.pdf (accessed on 20 August 2021).
85. Ibáñez, C.; Day, J.W.; Reyes, E. The response of deltas to sea-level rise: Natural mechanisms and management options to adapt to high-end scenarios. *Ecol. Eng.* **2014**, *65*, 122–130. [CrossRef]
86. IPCC. *Third Assessment Report: Climate Change 2001, Working Group II: Impacts, Adaptation and Vulnerability*; Cambridge University Press: Cambridge, UK, 2001.
87. USAID. *Adapting to Coastal Climate Change: A Guidebook for Development Planners*; Coastal Resources center–University of Rhode Island (cRc–URi) and International Resources Group (iRg): Washington, DC, USA, 2009.
88. Galofré, J. Set-back coastal measures, including geomorphological criteria, as a tool on integrated coastal zone management. In Proceedings of the VI Jornadas de Geomorfología Litoral, Tarragona, Spain, 7–9 September 2011.
89. Pranzini, E.; Wetzel, L.; Williams, A.T. Aspects of coastal erosion and protection in Europe. *J. Coast. Conserv.* **2015**, *19*, 445–459. [CrossRef]
90. Alvarado-Aguilar, D.; Jiménez, J.A.; Nicholls, R.J. Flood hazard and damage assessment in the Ebro Delta (NW Mediterranean) to relative sea level rise. *Nat. Hazards* **2012**, *62*, 1301–1321. [CrossRef]
91. Catalunya, G. (Ed.) *LLEI 8/2020, del 30 de Juliol, de Protecció i Ordenació del Litoral*; Diari Oficial de la Generalitat de Catalunya: Barcelona, Spain, 2020; Volume 8192, p. 21.
92. Giosan, L.; Syvitski, J.; Constantinescu, S.; Day, J. Protect the world's deltas. *Nat. Clim. Chang.* **2014**, *516*, 31–33.
93. Loucks, D.P. Developed river deltas: Are they sustainable? *Environ. Res. Lett.* **2019**, *14*, 113004. [CrossRef]

94. Platvoet, L. *Protection of European Deltas*; Committee on the Environment, Agriculture and Local and Regional Affairs, Ed.; Council of Europe: Strasbourg Cedex, France, 2005.
95. Day, J.W.; Colten, C.; Kemp, G.P. Mississippi delta restoration and protection: Shifting baselines, diminishing resilience, and growing nonsustainability. In *Coasts and Estuaries: The Future*; Elsevier: Amsterdam, The Netherlands, 2019; pp. 167–186. [CrossRef]
96. Comín, F.A.; Romero, J.A.; Hernández, O.; Menéndez, M. Restoration of Wetlands from Abandoned Rice Fields for Nutrient Removal, and Biological Community and Landscape Diversity. *Restor. Ecol.* **2001**, *9*, 201–208. [CrossRef]
97. Day, J.; Ibáñez, C.; Scarton, F.; Pont, D.; Hensel, P.; Day, J.; Lane, R. Sustainability of Mediterranean Deltaic and Lagoon Wetlands with Sea-Level Rise: The Importance of River Input. *Estuaries Coasts* **2011**, *34*, 483–493. [CrossRef]
98. Frihy, O.E. Evaluation of future land-use planning initiatives to shoreline stability of Egypt's northern Nile delta. *Arab. J. Geosci.* **2017**, *10*, 1–14. [CrossRef]
99. El Sayed, W.R.; Khalifa, A.M. Nile Delta Shoreline Protection between Past and Future. In *Proceeding of the 20thInternational Water Technology Conference*; International Water Technology Association, Ed. Publisher: London, UK, 2017.
100. Gâştescu, P. The Danube Delta biosphere reserve. Geography, biodiversity, protection, management. *Rev. Roum. Géogr.* **2009**, *53*, 139–152.
101. Stănică, A.; Dan, S.; Jiménez, J.A.; Ungureanu, G.V. Dealing with erosion along the Danube Delta coast. The CONSCIENCE experience towards a sustainable coastline management. *Ocean. Coast. Manag.* **2011**, *54*, 898–906. [CrossRef]
102. Nicholls, R.; Wong, P.P.; Burkett, V.R.; Codignotto, J.; Hay, J.; McLean, R.; Ragoonaden, S.; Woodroffe, C.D. Coastal systems and low-lying areas. In *Climate Change 2007: Impacts, Adaptation and Vulnerability*; Parry, M., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E., Eds.; Cambridge University Press: Cambridge, UK, 2007; pp. 315–356.
103. Anadón, R.A.; Danovaro, R.; Dippner, J.W.; Drinkwater, K.F.; Hawkins, S.J.; O'Sullivan, G.; Oguz, T.; Reid, P.C. *Impacts of Climate Change on the European Marine and Coastal Environment*; European Science Foundation: Strasbourg, France, 2007; pp. 1–84.
104. Shaltout, K.H.; Al-Sodany, Y.M.; Eid, E.M. Growth behaviour of the invasive species Ipomoea carnea in the Nile Delta, Egypt. *Hydrobiologia* **2010**, *656*, 187–197. [CrossRef]
105. Schrimpf, A.; Pârvulescu, L.; Copilaș-Ciocianu, D.; Petrusek, A.; Schulz, R. Crayfish plague pathogen detected in the Danube Delta—A potential threat to freshwater biodiversity in southeastern Europe. *Aquat. Invasions* **2012**, *7*, 203–510.
106. Costanza, R.; de Groot, R.; Sutton, P.; van der Ploeg, S.; Anderson, S.J.; Kubiszewski, I.; Farber, S.; Turner, R.K. Changes in the global value of ecosystem services. *Glob. Environ. Chang.* **2014**, *26*, 152–158. [CrossRef]
107. Mediterranean Wetlands. Land Cover-Spatial Dynamics in Mediterranean Coastal Wetlands from 1975 to 2005. Thematic Collection, 2014, Issue #2. Tour du Valat, France. 48 p. Available online: https://tourduvalat.org/en/dossier-newsletter/thematic-issue-land-cover-spatial-dynamics-in-mediterranean-coastal-wetlands-from-1975-to-2005/ (accessed on 12 October 2021).
108. Santos-Martin, F.; Montes, C. La evaluación de los ecosistemas del milenio de España. Del equilibrio entre la conservación y el desarrollo a la conservación para el bienestar humano. *Eubacteria* **2013**, *31*, 1–8.
109. Romagosa, F.; Pons, J. Exploring local stakeholders' perceptions of vulnerability and adaptation to climate change in the Ebro delta. *J. Coast. Conserv.* **2017**, *21*, 223–232. [CrossRef]