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Wetlands in Crisis: The Silent Desertification Threat on the Greek Wetlands

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Abstract: This study deals with the information gap on desertification risk for wetland habitat types in Natura 2000 network sites of Greece. Using the Environmentally Sensitive Areas (ESA) index as a proxy, all Natura 2000 wetland habitat types have been assessed and assigned to desertification risk categories. The assessment was conducted at the national, regional, and local scales in order to provide different outcomes for targeted support on decision and policy making regarding restoration and conservation measures. The main results document that circa 20% of wetland habitat types area are considered under desertification risk, while circa 10% are considered as potentially affected by desertification. It was also shown that there should be prioritization of the habitat types that need attention due to their inclusion in the different desertification risk categories. The study also highlights the administrative regions (NUTS2) and Natura 2000 sites and the need to structure, draft, and implement conservation projects to mitigate wetlands' risk as well as the use of wetlands as primary nature-based solutions (NbS) in the battle with desertification and climate change. Management implications are also provided from the perspective of habitat restoration as well as for their exploitation as valuable NbS for biodiversity conservation and ecosystem services maintenance.

Keywords: Natura 2000; ESA index; conservation priority; nature-based solutions; climate change; bioclimate; ecosystem services; support for decision making

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1. Introduction

Greek wetlands, vital ecosystems for biodiversity and water regulation, are facing significant challenges due to climate change and desertification. These wetlands are crucial for numerous species (supporting a rich diversity of flora and fauna, including species that are endemic, rare, or threatened) and provide essential ecosystem services like flood control, water purification, and carbon sequestration. Wetlands provide numerous environmental, social, and economic benefits, including water purification and flood control (see, e.g., [1,2]). However, two-thirds of Europe's wetlands have been lost in the past century due to urbanization, pollution, and land-use changes, making them among the most endangered ecosystems [3]. Climate change is a major threat to these ecosystems; rising temperatures and altered precipitation patterns are expected to exacerbate water scarcity, affecting wetland hydrology and the species dependent on these habitats [2]. Additionally, extreme weather events such as heatwaves and droughts are becoming more frequent and intense due to climate change, further stressing these delicate ecosystems.

Several studies have assessed the land degradation of wetland ecosystems using desertification models and indices in order to understand its primary drivers and processes

(see, e.g., [4,5]). Various models have been developed to assess desertification risk, e.g., the vegetation index [6], climate and vegetation indices [4], and drought assessment [5]. However, the MEDALUS framework has been a common approach to assess desertification in different studies worldwide (e.g., [7–10]) since it provides a flexible and easy-to-apply methodology that combines physical and socio-economic drivers of desertification [11,12].

The Mediterranean region, including Greece, faces severe desertification risks due to climatic changes, extreme weather events, and human activities such as overgrazing, intensive agriculture, and poor land-management practices [1,3]. These risks are evident also in Greek wetland areas, leading to land degradation in arid, semi-arid, and dry sub-humid areas, primarily due to human activities and climatic variations. In Greece, this is particularly evident in regions like Thessaly, where future climate scenarios predict an increase in desertification risk [13]. This process not only diminishes the ecological value of these areas but also affects agricultural productivity and the livelihoods of local communities. The Environmentally Sensitive Areas (ESAs) MEDALUS methodology has been used to assess desertification risk trends in Greece, revealing an increase in areas at critical risk of desertification over the past 45 years [14]. Specific regions such as the island of Lesvos and the prefecture of Kilkis have been studied to develop models combining climate, vegetation, soil, and management indicators into a unique desertification index, highlighting areas where prevention and mitigation actions are urgently needed [15,16]. The impact of future climate change on land degradation in Thessaly, a key agronomic zone, includes increased desertification risk, soil losses, and primary salinization, particularly in poorly drained soils [13]; simultaneously, mountainous areas such as the one near Vegoritis Lake in northwestern Greece suffer from severe soil erosion due to overgrazing, resulting in extremely low plant cover and further desertification [17]. Moreover, it should be noted that wetlands, are particularly vulnerable, facing degradation from pollution, agricultural intensification, and urban development despite being protected under the Ramsar Convention (see, e.g., the case of Lake Koronia (National Park in northcentral Greece) [18].

In addition, it is anticipated and well documented that future bioclimatic changes will bring about significant challenges and are likely to have adverse effects on agriculture, forest health, nature reserves and protected areas settings, and phenological occurrences associated with the existing flora and vegetation [19,20], further complicating the battle on desertification.

By this, Greek wetland areas, as nature-based solutions (NbS) [21,22] for mitigating land degradation and climate impacts, necessitate immediate and effective conservation and management strategies targeting to preserve these critical ecosystems and the services they provide. However, documentation focusing on the desertification risk in Greek wetland habitat areas is missing in order to spatially identify, prioritize, design, and implement relevant measures and actions.

The aim of this study is to fill the information gap on the desertification risk for wetland habitat types in Natura 2000 network sites of Greece. The objectives of the study include the following: (a) assess and prioritize habitat types under desertification risk to create the baseline information for areas needing resilience measures and actions for climate-change impact mitigation and ecosystem restoration, conservation, and/or amelioration; (b) provide information at national, regional, and local scales to support targeted conservation management; and (c) guide further research not only in ecology and conservation science but also in policy and decision making for spatial planning and natural capital-integrated management.

2. Materials and Methods

To assess the desertification risk in the Greek wetland ecosystems included in the Natura 2000 network, we assessed the Greek wetland ecosystems included and mapped in the Natura 2000 Special Areas of Conservation (SACs) at the habitat-type level. In this, we managed to include wetland areas present not only near main and major wetlands

(e.g., RAMSAR sites, river deltas, and lakes) but also the smaller wetland areas scattered throughout the Natura 2000 network of Greece [23].

In order to identify conservation and/or restoration priorities, the assessment was conducted at three scales, i.e., using (a) the Natura 2000 Network (national scale) [23], (b) the 13 Administrative Regions of Greece (NUTS2) [24] (regional scale), and (c) the 24 Natura 2000 NECCA (Natural Environment and Climate Change Agency) Management Units [25] (Natura 2000 site specific) (local scale).

2.1. Greek Natura 2000 Network Wetlands Datasets

For the identification and mapping of the Greek wetlands, we used the Natura 2000 habitat-type mapping dataset [26] filtered by the wetland habitat-type codes (Table 1) using the QGIS platform [27]. By this, we extracted the wetland habitat-type polygons, calculated their area extent, and created a thematic mapping overview of their distribution, simultaneously delineating the extent of the study area (Figure 1).

Table 1. Wetland habitat types of the Natura 2000 Network in Greece [28,29].

Habitat Type Group and Code	Habitat Type Name
Coastal and halophytic habitats	
1310	Salicornia and other annuals colonizing mud and sand
1410	Mediterranean salt meadows (Juncetalia maritimi)
1420	Mediterranean and thermo-Atlantic halophilous scrubs (Sarcocornetea fruticosi)
1430	Halo-nitrophilous scrubs (Pegano-Salsoletea)
1440 GR	Salt flats
1510 *	Mediterranean salt steppes (Limonietalia)
Coastal sand dunes and inland dunes	
2190	Humid dune slacks
Freshwater habitats	
3130	Oligotrophic to mesotrophic standing waters with vegetation of the Littorelletea uniflorae and/or Isoeto-Nanojuncetea
3140	Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp.
3150	Natural eutrophic lakes with Magnopotamion or Hydrocharition-type vegetation
3170 *	Mediterranean temporary ponds
3190 GR	Water body without vegetation
3240	Alpine rivers and their ligneous vegetation with *Salix elaeagnos*
3250	Constantly flowing Mediterranean rivers with *Glaucium flavum*
3260	Water courses of plain to montane levels with the Ranunculion fluitantis and Callitricho-Batrachion vegetation
3280	Constantly flowing Mediterranean rivers with Paspalo-Agrostidion species and hanging curtains of *Salix* and *Populus alba*
3290	Intermittently flowing Mediterranean rivers of the Paspalo-Agrostidion
32B0 GR	Euro-Siberian annual communities of muddy riverbanks
Natural and semi-natural grassland formations	
6420	Mediterranean tall humid herb grasslands of the Molinio-Holoschoenion
6430	Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels
Raised bogs and mires and fens	
7140	Transition mires and quaking bogs
7210 *	Calcareous fens with *Cladium mariscus* and species of the Caricion davallianae
7230	Alkaline fens
72A0 GR	Greek reed beds
72B0	Tall sedge communities

* Priority habitat types for conservation in the EU; GR: Greek habitat-type code (not included in Annex I of Dir. 92/43/EEC [28,30]).

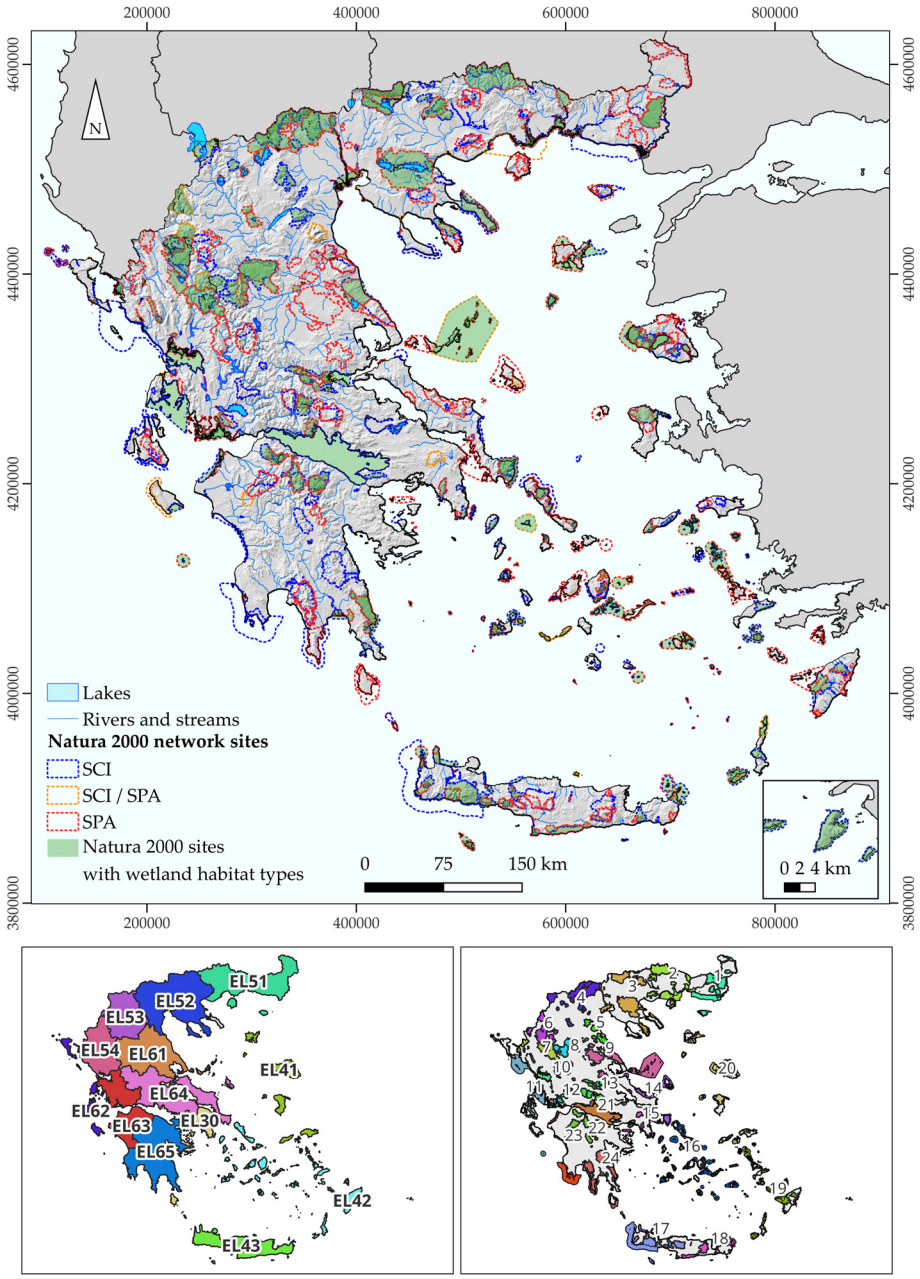


Figure 1. Map of Greece depicting the Natura 2000 network sites (top); with green color overlay, the Natura 2000 sites that include wetland habitats are presented, delineating the study area extent. Bottom left: Map depicting the 13 administrative regions of Greece (NUTS2), i.e., EL30 Attica, EL41 North Aegean, EL42 South Aegean, EL43 Crete, EL51 Eastern Macedonia and Thrace, EL52 Central Macedonia, EL53 Western Macedonia, EL54 Epirus, EL61 Thessaly, EL62 Ionian Islands, EL63 Western Greece, EL64 Central Greece, and EL65 Peloponnese. Bottom right: Natural Environment and Climate Change Agency Management Units, i.e., 1-Management Unit of Evros Delta and Dadia National Parks, 2-Management Unit of Nestos-Vistonida and Rhodope National Parks, 3-Management Unit of Protected Areas of Central Macedonia, 4-Management Unit of Prespa National Park and Protected Areas of Western Macedonia, 5-Management Unit of Olympus National Park, 6-Management Unit of Northern Pindos National Park, 7-Management Unit of the Protected Areas of Epirus, 8-Management Unit of Protected Areas of Thessaly, 9-Management Unit of Sporades National Park, 10-Management Unit of Acheloos Valley and Amvrakikos Gulf Protected Areas,11-Management Unit of Zakynthos and Ainos National Parks and Protected Areas of the Ionian Islands, 12-Management Unit of Messolonghi National Park and Protected Areas of Western Central Greece, 13-Management Unit of Parnassos and

Oiti National Parks and Protected Areas of Eastern Central Greece, 14-Management Unit of Skyros and Evia Protected Areas, 15-Management Unit of Parnitha and Schinias National Parks and Protected Areas of Saronikos Gulf, 16-Management Unit of the Central Aegean Protected Areas, 17-Management Unit of Samaria National Park and the Protected Areas of Western Crete, 18-Management Unit of Eastern Crete Protected Areas, 19-Management Unit of the Southeastern Aegean Protected Areas, 20-Management Unit of The Northeastern Aegean Protected Areas, 21-Management Unit of The Corinthian Gulf, 22-Management Unit of Chelmos—Vouraikos National Park And Protected Areas of The Northern Peloponnese, 23-Management Unit of Strofylia Wetlands National Park and Protected Areas of Western Peloponnese, and 24-Management Unit of The Southern Peloponnese Protected Areas.

2.2. Desertification Assessment

The desertification impact on Greek Natura 2000 wetland habitat types was assessed using the dataset raster of the desertification risk in Greece provided by the European Commission Joint Research Centre–European Soil Data Centre (ESDAC) [31]. This dataset includes information on the different desertification risk categories present in the Greek territory, i.e., not affected (N), potentially affected (P), fragile level 1 (F1), fragile level 2 (F2), fragile level 3 (F3), critical level 1 (C1), critical level 2 (C2), critical level 3 (C3), and all other areas (Other). These categories and their spatial distribution across Greece are the results of the qualitative assessment on desertification risk in Greece via the ESA index, which exploited the Environmentally Sensitive Areas (ESAs) data of MEDALUS methodology; this methodology generally combines four independent indices for climate, soil, vegetation, and land-management quality to produce the composite ESA index as the result of their geometrical average [14].

A GIS zonal statistics analysis was conducted by intersecting the ESA index raster dataset with the wetland habitat types' vector polygons and extracting the prevailing value of the ESA index for each wetland habitat-type polygon within the QGIS platform [27]. Statistics for the ESA index for all wetland habitat types and for their area cover were calculated for three different scales, i.e., (a) wetland habitat types of the Natura 2000 network, (b) NECCA Management Units, and (c) administrative regions (NUTS2), in order to make the relevant prioritizations to support decision making for conservation, management, and policy actions.

In this way, wetland habitat-type area and percentages were calculated for each corresponding desertification risk (ESA index) category and for each respective habitat type at all three scales of the analysis.

Based on the aforementioned methodology, a thematic map of the ESA index on Greek Natura 2000 wetland habitat types' areas was also prepared using the QGIS platform [27].

3. Results

3.1. Desertification Risk of the Greek Natura 2000 Wetland Area at the National Scale

A significant part of the Greek wetlands is considered sensitive to desertification (17.24%; 13,548.98 ha) or at critical desertification risk (2.90%; 2279.59 ha), distributed accordingly to the three respective sensitivity levels presented in Table 2 Additionally, 9.60% (7546.39 ha) of the Greek wetland area is considered potentially affected by desertification. Finally, 7.45% (5855.05 ha) of the wetland area is considered not affected by desertification. It should be noted that 59.42% (46,752.35 ha) of the wetland area is classified under the "other areas" category; thus, it could not be assigned to a desertification risk category. For 78,633.30 ha (3.41%) of the wetland area, no data were available for the assessment.

The results of this assessment are presented in a thematic map (Figure 2), depicting as centroids the wetland areas (wetland habitat types) and their inclusion in the different desertification risk (ESA index) categories. It is highlighted that most habitat areas in critical risk are in northern Greece, followed by northwestern Greece and the central Aegean Islands (Kiklades Islands). Areas sensitive to desertification are widespread in northern Greece, the Peloponnisos, Crete, and the East Aegean Islands.

Table 2. Desertification risk categories (ESA index) of the wetland area in the Natura 2000 SAC, SAC/SPA of Greece.

ESA Index	Wetland Area (ha)	% of Total Wetland Areas in Greece
N: Not affected	5855.05	7.45%
P: Potentially affected	7546.39	9.60%
F: Fragile	13,548.98	17.24%
F1: Fragile level 1	*3487.55*	*4.44%*
F2: Fragile level 2	*7894.11*	*10.04%*
F3: Fragile level 3	*2167.32*	*2.76%*
C: Critical	2279.59	2.90%
C1: Critical level 1	*546.71*	*0.70%*
C2: Critical level 2	*785.95*	*1.00%*
C3: Critical level 3	*946.93*	*1.20%*
Other areas	46,725.35	59.42%
N/A	2677.93	3.41%
Toal wetland area in the Natura 2000 SAC, SAC/SPA areas of Greece	78,633.30	100.00%

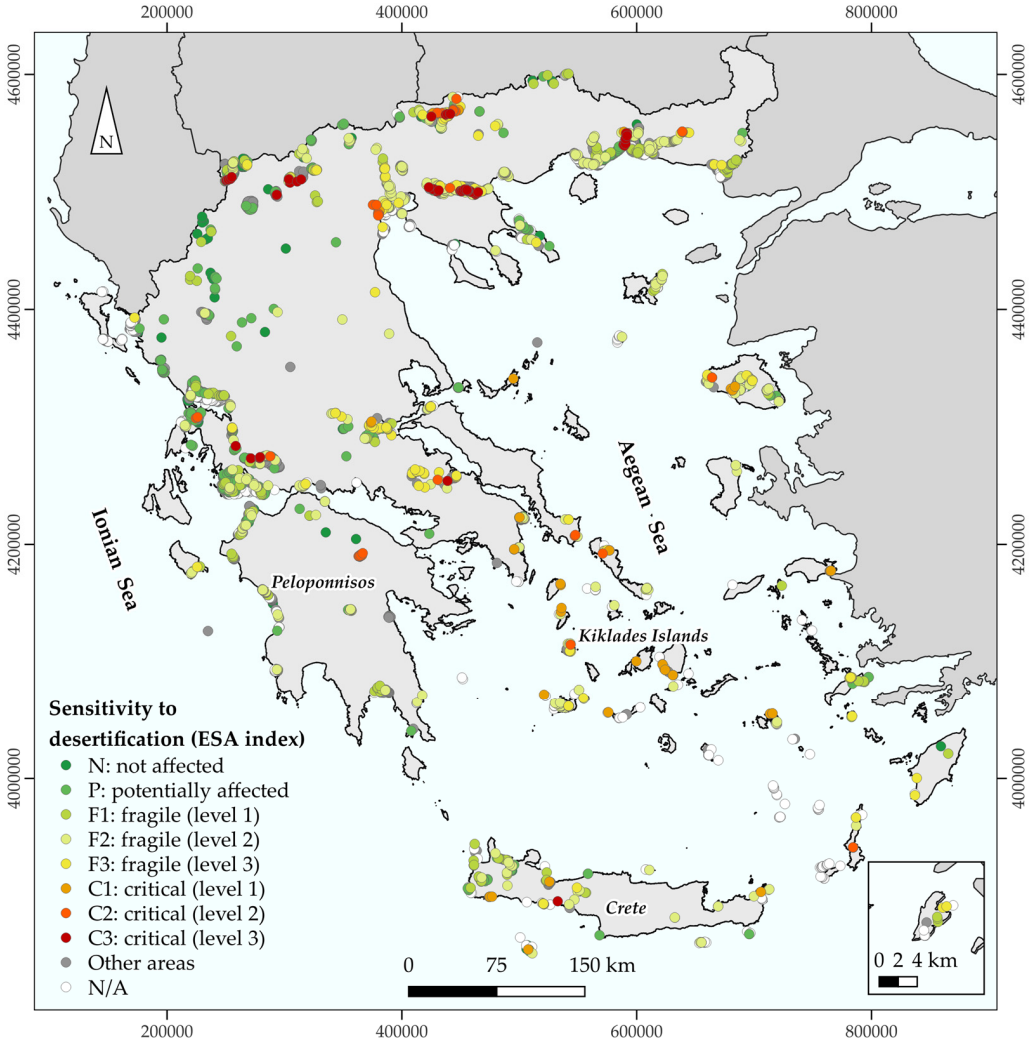


Figure 2. Sensitivity to desertification of the wetland areas (wetland habitat types) in the Natura 2000 SAC, SAC/SPA of Greece. Colored dots on map represent the centroids (selected for thematic representation purposes) of the wetland habitat-types polygons.

Desertification Risk of the Natura 2000 Wetland Habitat Types at the National Scale

The most critically sensitive to desertification (ESA index C-critical categories) habitat types at the national scale are 6420 "Mediterranean tall humid herb grasslands of the Molinio-Holoschoenion", 3130 "Oligotrophic to mesotrophic standing waters with vegetation of the Littorelletea uniflorae and/or Isoeto-Nanojuncetea", and 3280 "Constantly flowing Mediterranean rivers with Paspalo-Agrostidion species and hanging curtains of Salix and Populus alba", with their areas belonging in one of the ESA index critical categories (C1, C2, or C3) at percentages of 18.35%, 16.95%, and 9.91%, respectively. The habitat types 72A0 "Greek reed beds" and 1420 "Mediterranean and thermo-Atlantic halophilous scrubs (Sarcocornetea fruticosi)" follow with percentages of 5.04% and 2.58, respectively (Table 3). Regarding the sensitive-to-desertification F (fragile) category (ESA index categories F1, F2, or F3), most habitat types areas are affected at percentages above 15%. The most affected areas are recorded for the habitat types 3140 "Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp.", 3250 "Constantly flowing Mediterranean rivers with *Glaucium flavum*", and 3290 "Intermittently flowing Mediterranean rivers of the Paspalo-Agrostidion". The least affected habitat type is 7140 "Transition mires and quaking bogs"; however, it is considered potentially affected by desertification in its total area. A detailed table with the area and percentages for each respective ESA index category is provided in Table S1 of the Supplementary Materials.

Table 3. Greek wetlands habitat types' desertification risk (area and percentage).

Natura 2000 Habitat Type Code	N (ha)	N (%)	P (ha)	P (%)	F (%)	F (ha)	C (%)	C (ha)	Other (%)	Other (ha)	No Data (%)	No Data (ha)	Total (ha)
1310	230.57	6.16%	298.24	7.97	703.87	18.80%	14.33	0.38%	2130.60	56.91%	366.24	9.78%	3743.85
1410	1539.22	15.57%	1742.78	17.63	2374.15	24.02%	-	-	3626.01	36.69%	555.91	5.62%	9883.70
1420	731.11	6.37%	695.34	6.06	1765.58	15.39%	295.45	2.58%	6981.26	60.87%	1000.53	8.72%	11,469.28
1430	-	-	0.05	0.02	-	-	-	-	15.05	6.45%	214.12	91.80%	233.24
1440	1016.30	42.76%	-	-	-	-	-	-	840.31	35.35%	153.98	6.48%	2376.93
1510 *	-	-	-	-	-	-	-	-	356.89	99.30%	2.08	0.58%	359.42
2190	0.95	0.24%	7.27	1.81	131.75	32.78%	-	-	248.38	61.79%	10.18	2.53%	401.98
3130	-	-	-	-	-	-	-	-	130.37	81.14%	0.1	0.06%	160.67
3140	-	-	-	-	-	-	-	-	11.59	3.49%	0.08	0.02%	332.49
3150	97.78	1.06%	289.22	3.14%	236.74	2.57%	106.02	1.15%	8488.14	92.08%	0.73	0.01%	9218.63
3170 *	3.24	3.25%	3.33	3.33%	17.20	17.25%	1.59	1.59%	71.39	71.58%	2.99	3.00%	99.73
3190 [GR]	142.96	0.87%	1676.14	10.19%	433.53	2.64%	1.98	0.01%	14,169.00	86.12%	28.31	0.17%	16,451.93
3240	15.47	11.57%	111.7	83.49%	-	-	-	-	-	-	-	-	133.78
3250	0.45	8.84%	0.09	1.84%	-	-	-	-	-	-	-	-	5.03
3260	284.71	29.65%	-	-	20.25	2.11%	-	-	655.3	68.24%	-	-	960.33
3280	211.08	7.59%	298.91	10.75%	1230.73	44.28%	-	-	763.25	27.46%	-	-	2779.42
3290	23.2	5.86%	12.73	3.22%	296.88	75.03%	-	-	62.27	15.74%	-	-	395.7
32B0 [GR]	-	-	20.53	2.50%	-	-	-	-	564.87	68.68%	-	-	822.48
6420	191.04	4.33%	382.89	8.69%	1728.63	39.22%	808.82	18.35%	1285.12	29.16%	11.12	0.25%	4407.62
6430	82.26	26.99%	74.06	24.30%	143.78	47.18%	-	-	-	-	4.66	1.53%	304.76
7140	-	-	1	100.00%	-	-	-	-	-	-	-	-	1
7210 *	-	-	222.27	91.72%	-	-	-	-	15.7	6.48%	1.59	0.65%	242.34
7230	41.26	35.47%	62.93	54.10%	-	-	-	-	10.89	9.36%	-	-	116.32
72A0 [GR]	1218.94	8.95%	1638.25	12.03%	3474.84	25.52%	685.98	5.04%	6273.22	46.07%	325.32	2.39%	13,616.55
72B0	24.51	21.11%	8.68	7.47%	-	-	-	-	25.75	22.17%	-	-	116.11
Total	5855.05	7.45%	7546.39	9.60%	13,548.98	17.23%	2279.59	2.90%	46,725.35	59.42%	2677.93	3.41%	78,633.30

*: Priority habitat types for conservation in the EU; [GR]: Greek habitat- type code (not included in Annex I of Dir. 92/43/EEC [28,30]).

It should be highlighted that habitat type 6420 is in the level 3 critical category (C3) at a percentage of 9.42% of its area, in C2 at 5.04%, C1 at 3.90%, F3 at 1.26%, F2 at 25.35%, and in F1 at 12.61%. It should also be noted that for the habitat types of priority importance for conservation in the EU (i.e., 1510*, 3170*, and 7210*), the majority of the areas covered by 1510* and 3170* (99.30% and 71.58%, respectively), could not be assigned to a desertification risk category and are characterized as "other areas". However, a significant part of 3170* (17.24%) is included in the sensitive (fragile)-to-desertification category (F). For the priority habitat type 7210*, the case is different, with most of its area (91.72%) considered potentially affected by desertification (P) (see also Table S1).

3.2. Desertification Risk of the Greek Natura 2000 Wetland Area at the Regional Scale

The assessment at the regional (NUTS2) administrative level identified the following desertification risk status for the wetland habitat types at each NUTS2 region: (a) When considering the critical desertification risk category (C), the South Aegean region (EL42), is considered the most affected, followed by the region of Crete (EL43) and Central Greece (EL64); (b) when considering the sensitive-to-desertification risk category (F), the region of Thessaly (EL61) has most of its wetland areas in this category, followed by the region of Attica (EL30) and the South Aegean region (EL42); (c) when all desertification risk categories are simultaneously considered, i.e., critical (C), sensitive (F), and potentially affected (P), the most affected region is the region of Thessaly (EL61), followed by the region of Attica (EL30) and the South Aegean region (EL42). Cumulatively considering all desertification risk categories, the least affected region is the region of the Ionian Islands (EL62), followed by the region of Epirus (EL54). Detailed data are presented in Table 4, and the relevant thematic representation is depicted in Figure 3 (for detailed data and analysis see Table S2).

Table 4. Greek wetlands habitat types' desertification risk (area and percentage) in each NUTS2 administrative region of Greece.

NUTS2	N		P		F		C		Other		F + C		F + C + P		Total
	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha
EL30	-	-	15.90	2.65%	419.69	69.97%	4.96	0.83%	47.34	0.08	424.65	70.80%	440.55	73.45%	599.77
EL41	17.37	0.89%	5.25	0.27%	683.91	35.14%	35.65	1.83%	1175.28	0.60	719.57	36.97%	724.82	37.24%	1946.37
EL42	0.22	0.05%	8.66	1.97%	242.54	55.14%	17.60	4.00%	27.96	0.06	260.14	59.14%	268.80	61.11%	439.85
EL43	9.99	3.53%	26.70	9.44%	132.28	46.75%	9.74	3.44%	77.77	0.27	142.02	50.20%	168.73	59.64%	282.93
EL51	1045.42	8.43%	1090.97	8.79%	3178.87	25.62%	4.90	0.04%	6644.31	0.54	3183.77	25.66%	4274.75	34.46%	12,406.28
EL52	327.07	1.76%	697.93	3.76%	3245.24	17.46%	349.66	1.88%	12,735.53	0.69	3594.89	19.34%	4292.82	23.10%	18,584.90
EL53	234.19	7.50%	137.38	4.40%	605.77	19.41%	0.08	0.00%	1889.79	0.61	605.85	19.41%	743.24	23.81%	3121.13
EL54	1447.09	15.78%	781.75	8.53%	560.89	6.12%	0.00	0.00%	5699.62	0.62	560.89	6.12%	1342.64	14.64%	9168.66
EL61	15.47	2.81%	98.89	17.97%	410.05	74.53%	2.45	0.44%	22.77	0.04	412.49	74.97%	511.38	92.95%	550.18
EL62	48.35	19.29%	0.40	0.16%	27.71	11.06%	0.00	0.00%	18.06	0.07	27.71	11.06%	28.11	11.22%	250.58
EL63	2593.89	10.78%	4493.59	18.68%	1954.49	8.12%	0.00	0.00%	14,199.86	0.59	1954.49	8.12%	6448.07	26.80%	24,057.68
EL64	24.45	0.41%	173.46	2.94%	1711.47	29.05%	121.82	2.07%	3730.80	0.63	1833.28	31.12%	2006.74	34.06%	5891.56
EL65	91.55	6.87%	15.50	1.16%	376.09	28.21%	0.28	0.02%	456.25	0.34	376.37	28.23%	391.88	29.39%	1333.40
Total	5855.05	7.45%	7546.39	9.60%	13,548.99	17.23%	546.73	0.70%	46,725.35	0.59	14,095.72	17.93%	21642.11	27.52%	78,633.30

3.3. Desertification Risk of the Greek Natura 2000 Wetland Area at the Local Scale

The local-scale assessment (at the NECCA Management Unit level) highlighted that the Management Units having most of their wetland habitats types (in terms of percentage of their total wetland habitat type area under their responsibility) in the ESA index critical (C) category are the (a) Management Unit of Chelmos–Vouraikos National Park And Protected Areas of The Northern Peloponnese, (b) Management Unit of Olympus National Park, (c) Management Unit of Parnitha and Schinias National Parks and Protected Areas of Saronikos Gulf, (d) Management Unit of Skyros and Evia Protected Areas, (e) Management Unit of the Southeastern Aegean Protected Areas, and (f) Management Unit of Sporades National Park.

Figure 4 depicts a diagram representing the wetland habitat-type area (%) per NECCA Management Unit at each desertification risk (ESA index) category.

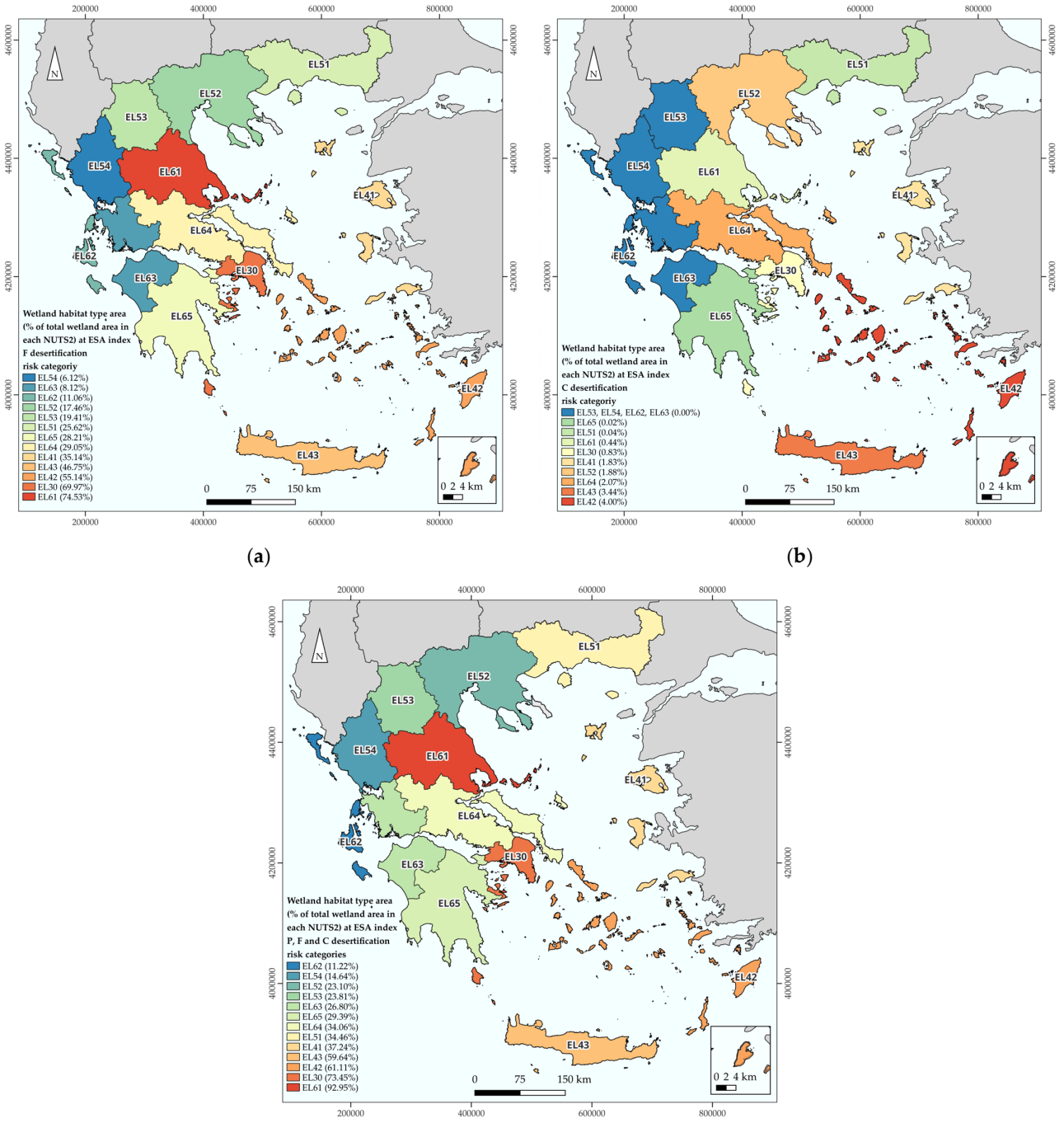


Figure 3. Greek wetlands habitat types' area at different ESA index categories, expressed as the percentage (%) per total wetland habitat types area at each NUTS2 administrative region of Greece: (**a**) Sensitive to desertification (ESA index F category); (**b**) critical desertification risk (ESA index C category); (**c**) cumulative percentage in the categories of fragile (F), critical (C), and potentially affected by desertification (P).

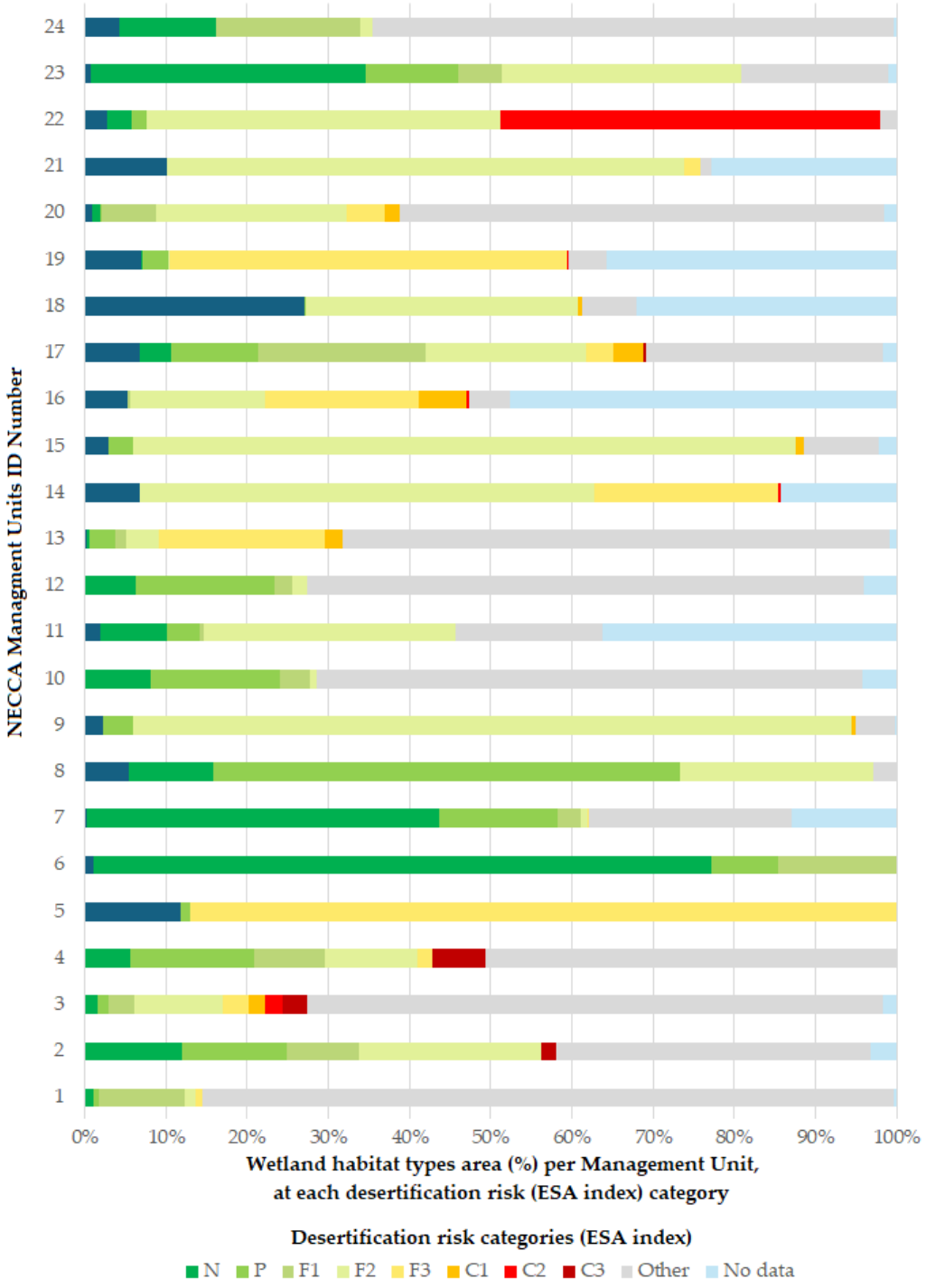
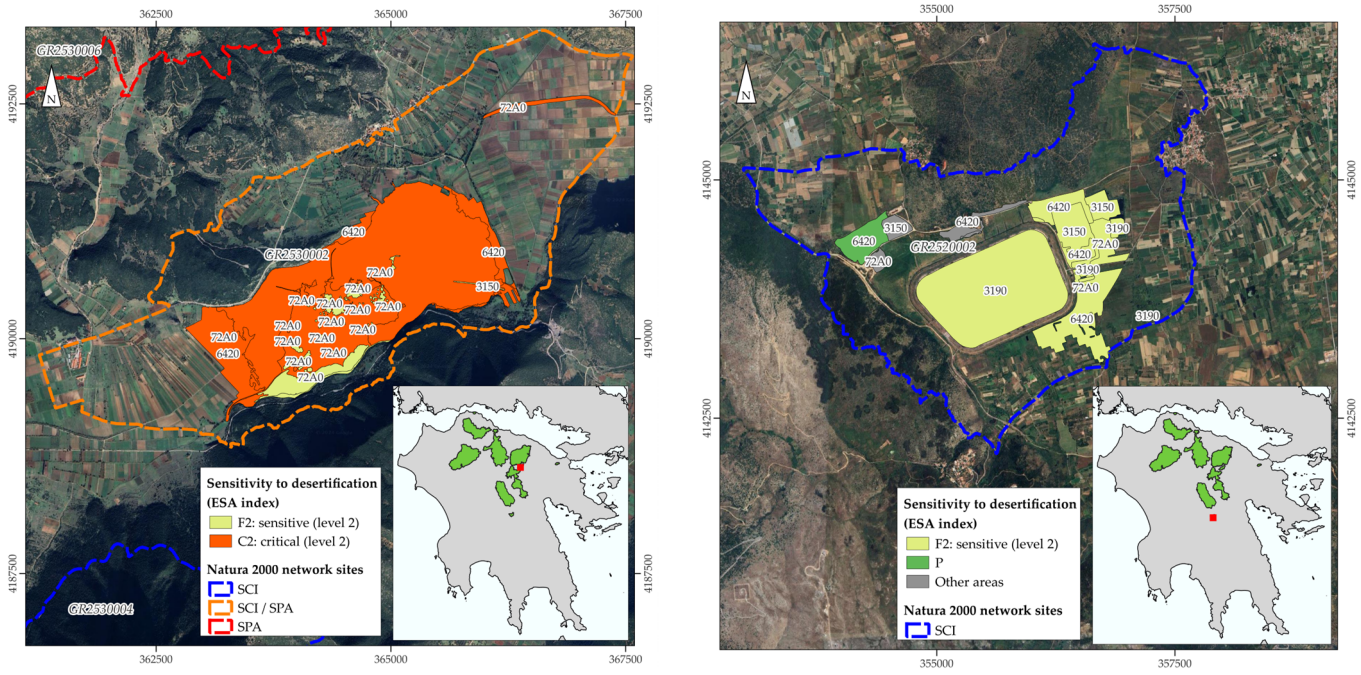


Figure 4. Diagrammatic representation of wetland habitat-type area (%) per NECCA Management Unit in each desertification risk (ESA index) category.

Two characteristic examples from the Management Unit of Chelmos–Vouraikos National Park And Protected Areas of The Northern Peloponnese are presented in Figure 5, depicting the spatial distribution of the assessed habitat types and the respective ESA index results.



(**a**) (**b**)

Figure 5. Two characteristic examples of wetland habitat types affected by desertification in the responsibility area of NECCA Management Unit 22 (Management Unit of Chelmos–Vouraikos National Park and Protected Areas of The Northern Peloponnese): (**a**) Natura 2000 SCI/SPA "Lake Stymfalia" (GR2530002); (**b**) Natura 2000 SCI "Lake Taka" (GR2520002). Four-digit codes correspond to the respective wetland habitat types (see Table 1).

4. Discussion

The present study performed for the first time an overview of the desertification risk of the wetland habitat types in the Natura 2000 protected area network of Greece. It was documented that a significant part (circa 20%) of wetland habitat-types area, including 22 Annex I of Dir. 92/73/EEC [30] habitat types (with three of those being of priority importance for conservation in EU, i.e., 1510*, 3170*, and 7210*, and three of national importance, i.e., 3190, 32B0, and 72A0) is considered under desertification risk, while circa 10% is considered potentially affected by desertification. The assessment at the national (Natura 2000 network), regional (NUTS2), and local (MU) levels highlighted that different priorities are needed when considering implementation measures for wetland conservation, restoration, and/or resilience building at the different scales. However, any management approaches and decisions on strategies, measures, and actions for wetland restoration, conservation, and exploitation as nature-based solutions should consider future climatic projections and bioclimatic shifts, which are already well documented for Greece [19] and exemplified for specific Natura 2000 wetland-dominated sites, incorporating water-management scenarios such as, e.g., in the cases of the protected areas of Lakes Stymfalia (the Peloponnese) [32], Trichonida (western Greece) [33], Cheimaditida (western Macedonia), and Kerkini (central Macedonia) [34].

4.1. Conservation Responsibility for the Wetland Habitat Types in Greece

In the study by Dimopoulos et al. [35] on national conservation responsibility for the habitat types present in the Greek Natura 2000 network, the wetland habitat types that are of priority for conservation in Greece were listed. According to this list, eleven (11) wetland habitat types (i.e., 1510*, 2190, 3130, 3140, 3170*, 3260, 3280, 32B0, 6420, 6430, and 7210*) were assigned to be of high importance for conservation in Greece, and eight (8) habitat types (i.e., 1310, 1410, 1420, 1440, 3150, 3240, 3290, and 72A0) were assigned to the

medium-conservation-responsibility category. From these habitat types, 3130, 3280, and 6420 were also considered to be in areas at critical risk for desertification, while the habitat types of priority for conservation by the EU are under desertification risk in some areas (in sensitive or critical categories), i.e., 1510*, 3170*, and 7210*. In particular, the habitat type 3170* "Mediterranean temporary ponds" is already under management implementation action via the ForOpenForests Life Project in the Natura 2000 sites GR2440004 "Ethnikos Drymos Oitis" (National Park of Mt. Oiti) and in GR2440006 "Oros Kallidromo" (Mt. Kallidromo) [36]. However, in other areas where the desertification risk is critical for this habitat, i.e., in GR4110004, GR4220010, and GR4340013, it is suggested to immediately assess the areas with field surveys to document their condition and subsequently design and implement restoration and/or conservation measures in order to safeguard this scattered, small-surfaced priority habitat type.

4.2. Wetland Restoration as a Nature-Based Solution in the Climate Crisis Era

Wetland habitat types should always be considered not only as areas of particular importance for biodiversity and ecosystem functioning but also as a NbS that can play a pivotal role in achieving multiple Sustainable Development Goals (SDGs), such as clean water and sanitation, climate action, and sustainable cities and communities. By reducing greenhouse gases, filtering environmental toxins, and maintaining stable water tables, wetlands contribute to the overall health and resilience of ecosystems [1]. To effectively combat desertification in Greece, it is essential to adopt a nexus approach that integrates wetland conservation and restoration into broader land-use planning and management strategies. This approach should consider the interactions between SDGs and their targets, moving beyond a "business as usual" mindset to harness the full potential of wetland ecosystems in addressing environmental challenges [1]. To exemplify this, and in particular for the areas identified as a priority for measures and actions, at the local scale, i.e., the Natura 2000-protected area of Lake Stymfalia "GR2530002", Kokkoris et al. [32] proposed a scenario-building approach including natural resources-management scenarios, natural resources demand scenarios, and climatic scenarios for the integrated development of the area, giving priority to wetland ecosystem health, which supports all aspects of ecosystem services in the region. The same focus should be given to the constructed wetlands of the Natura 2000 network, having as an example the protected area of Lake Taka (GR2520002), with its wetland area being mainly sensitive to desertification. The use of constructed wetlands, as a primary NbS, can address multiple environmental challenges while providing economic and societal benefits. The conservation, restoration, and amelioration of constructed wetlands can be integrated into the agri-food supply chain to offer eco-innovative solutions for sustainable development in the post-COVID-19 era [37]. It is evident that during any management approach, climate-change projections at the most detailed available scale should be taken into account (see, e.g., [2,38]) to design successful mid- and long-term measures and actions, integrating relevant information for other landscape-shaping parameters, e.g., wildfires that dominate in Mediterranean environments (see, e.g., [39]). After all, knowledge of the nature of climatic and ecological changes that are likely to occur at the national or regional level is crucial in order to properly design wetland-management and relevant restoration plans [40]. In this context, the project "LIFE-IP AdaptInGR—Boosting the implementation of adaptation policy across Greece" developed future climatic projection models and designed a web–GIS platform for climate-change indices for the Greek territory [41,42] and freely provides this information to any interested party. Moreover, a detailed study on future bioclimatic conditions in Greece, with a special focus on the floristic regions of Greece, was made available by Charalampopoulos et al. [19], which can support the design and spatial distribution of wetland NbS based on the estimated shifts of the bioclimatic zones.

4.3. Management Implications

Understanding the hydrology, soils, and biodiversity of these ecosystems is crucial for effective wetland management (see, e.g., [43]). Many Greek wetlands have been degraded by agricultural expansion, urban development, and water pumping. Management efforts should focus on mitigating these impacts and promoting natural restoration processes [44]. Wetland restoration techniques include restoring natural water flow, replanting native vegetation, and controlling invasive species. The success of these techniques depends on a thorough understanding of the ecological dynamics of the wetland [45]. Moreover, we should always consider that the herein-presented approach is based on an index that incorporates scale and modeling limitations and assumptions. By this, field-based assessments are pivotal in the examination of desertification and land-degradation phenomena at the local scale. Quantitative analyses of soil characteristics, including organic matter concentration, salinity, and water-retention capabilities, serve as critical indicators of land degradation within wetland ecosystems (see, e.g., [46]). Furthermore, the evaluation of biodiversity fluctuations, specifically the decline of species reliant on wetland habitats, may serve as a key indicator of the emergence of desertification [47,48]. Ongoing monitoring is essential to evaluate the effectiveness of restoration efforts and to adapt management strategies as needed. This includes monitoring changes in water quality, vegetation, and wildlife populations.

Engaging local communities in wetland-management projects can enhance public awareness and support for conservation efforts. This includes educating communities about the value of wetlands and involving them in restoration activities [49]. Raising public awareness and public participation is considered of high priority, especially for the Natura 2000 network sites, as highlighted in Kokkoris et al. [50], in Greece and throughout Europe. The enactment of appropriate, supportive legislation and adequate funding are critical to the successful implementation of wetland restoration projects, which, in addition to being targeted small-scale projects, can be large in scale (e.g., reflooding of lakes and old wetlands) and duration, often creating controversy over new land uses [51,52].

Following the results of the present study for the three scales of the assessment and for a standardized, coherent, and robust design and implementation of conservation measures and actions, it is suggested to draft a master plan for each specific group of wetland habitat types, i.e., for (a) coastal and halophytic habitats, (b) coastal sand dunes and inland dunes, (c) freshwater habitats, (d) natural and semi-natural grassland formations, and (e) raised bogs and mires and fens. This task should be assigned to the coordinating authority of the Natura 2000 network in Greece, i.e., the Natural Environment and Climate Change Agency (NECCA). Within this task, NECCA will describe what measures and actions should be implemented, provide a timetable (including milestones) for each activity, and designate responsible authorities for implementation (e.g., Administrative Regions, NECCA Management Units) in order to also allocate and leverage relevant resources. This process should take into account the provisions of the Prioritised Action Framework (PAF) for Natura 2000 in Greece (or the Multiannual Financial Framework period 2021–2027) [53] as well as the Greek National Action Plan for Combating Desertification [54], which, along with other national and international strategies (e.g., Common Agricultural Policy, Soil Strategy, and Biodiversity Strategy), aims to provide the necessary measures to mitigate land degradation, emphasizing the need for sustainable land-management practices and the protection of valuable soil and water resources [55]. Additionally, the recently adopted EU Nature Restoration Law [56], alongside the provisions of the European Green Deal [57], should be used to prioritize the proposed measures and actions in the decision-making process and in the central policy agenda. The current structure of protected area governance via the decentralized NECCA Management Units provides the required framework for a bottom-up approach to identifying local-scale needs and cooperating with regional authorities, with simultaneous top-down support from administrative and financial resources as coordinated by the central Agency (NECCA).

5. Conclusions

Greek wetlands, a significant part of the national natural capital and of the Natura 2000 network in Greece, face multiple threats, among which is the risk of desertification and land degradation. The results of this study identified wetland areas in the Natura 2000 network that need attention in order to mitigate this risk and guide targeted, scientifically based decision making for their management. It was also highlighted that habitats of priority importance at the EU and national levels are at risk, and the conservation responsibility of the Greek authorities should be addressed at different implementation scales, from the local to the regional and national scales. Moreover, management implications were discussed on the potential of Greek wetlands to provide full-scale nature-based solutions to combat land degradation and desertification in arid and semi-arid Mediterranean regions, where future bioclimatic changes are well documented. Future research should focus on local-scale measurements and data collection on desertification status and/or potential risk to better streamline prevention, mitigation, and restoration strategies and actions. Finally, this study acts as a pilot for identifying areas where priority should be given for the implementation of the recently adopted EU Nature Restoration Law and for the measures and actions included in the European Grean Deal framework.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land13101567/s1, Table S1: Natura 2000 wetland habitat types in the different ESA index categories; Table S2: Administrative Regions of Greece (NUTS2) wetland habitat-types' area in the ESA index.

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