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Environmental Sustainability Analysis of Land Use/Land Cover Change Using the WEI Index: Application to the Municipalities around the Doñana Area in Spain

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Abstract: This paper presents a novel definition of the Weighted Environmental Index (WEI) specifically adapted to integrate with the official land use and land cover (LULC) cartographic historical database employed in Andalusia. This adapted WEI framework was applied to investigate land use changes within municipalities surrounding the Doñana area (South of Spain). The analysis focused on the period 1991–2016, with a detailed examination of land use modifications in thirteen individual municipalities. The results demonstrate the WEI's adaptability in incorporating information from diverse databases. Furthermore, they highlight the importance of integrating the analysis of WEI evolution over time. This combined approach facilitates a deeper understanding of the socio-economic and environmental drivers influencing land use changes in municipalities around the Doñana area. The findings reveal a sustained decrease in WEI values over the analyzed period. This decline is attributed to the expansion of irrigated cropland at the expense of rain-fed agriculture. Additionally, a significant increase in greenhouse surface area was observed. This intensification of agriculture has contributed to aquifer overexploitation, with potential environmental consequences for the Doñana area.

Keywords: land use/land change; WEI index; Doñana area

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1. Introduction

One of the most sensitive and fragile environmental areas in Spain is the Doñana area. The Doñana area is administratively delimited by the Territorial Planning Plan of the Doñana Area (defined by Law 7/2021, of December 1, for the promotion of the sustainability of the territory of Andalusia) [1].

In the Doñana area, in addition to the municipalities that are part of it, there is the Doñana Natural Space. Declared in 1999, it is comprised of the Doñana Natural Park and the Doñana National Park [2]. The Doñana Natural Space is one of the most important protected areas in the Andalusian territory and the largest ecological reserve in Europe, hosting a unique biodiversity, with some emblematic species such as the Iberian lynx (*Lynx pardina*) and the Iberian imperial eagle (*Aquila adalberti*), which are currently endangered [3]. Additionally, it is part of the Natura 2000 Network as a Special Conservation Area (SCA) and Special Protection Area for Birds (SPAB) and is internationally recognized as a Biosphere Reserve. It is a Ramsar Wetland, and the National Park is a UNESCO World Heritage Site [4]. In addition to this, the area serves as an important stopover point on the migratory route of birds traveling between Europe and Africa [5].

The Doñana area encompasses areas of high ecological and environmental value. However, it faces numerous pressures and impacts, with land occupation and use for human activities, primarily agriculture, posing the greatest threats. The ongoing territorial tensions in the area are largely linked to a gradual process of soil anthropization, increasingly encroaching upon ecologically sensitive natural areas [6]. Thus, the existence of high-quality and fragile ecosystems (marshes, dunes, forests, and coastline) gives the area an ecological and environmental uniqueness that makes it unique in the world [7].

Since the awareness of the need to protect its natural and environmental values in the mid-20th century, which materialized with the creation of the National Park in 1969, an intense planning process has been developed in the area in question; so much so that no other area in Spain has been subjected to such a degree of public intervention. The extreme fragility of the ecosystems of Doñana and the fact that it constitutes the most important wetland in the European continent have been, on the one hand, the main motivations for such interventions. On the other hand is the need to make compatible the existence of these natural areas and the normal development of their ecological processes with the growth and economic development of the area, in which the municipalities that make it up are key elements of these territorial processes [8].

Driven by the ecological importance of the Doñana area as a unique ecosystem and biosphere reserve, this study employed the Weighted Environmental Index (WEI) [9,10] to analyze the evolution of the territory's environmental value. The WEI is designed to integrate comprehensive information from extensive and detailed Geographic Information System (GIS) databases. In this research, land use information was drawn from the Map of Land Uses and Vegetation Cover in Andalusia (MUCVA) [11]. To facilitate this integration, the original WEI formulation required an update, as explained subsequently.

Environmental indicators have become a ubiquitous evaluation tool across national, regional, local, and field levels [12]. These indicators empower decision-makers with the information necessary to make informed judgments about policies, programs, plans, and projects [13]. Notably, a key advancement in protected area conservation involves the use of environmental indicators to assess management effectiveness [14]. Monitoring programs incorporating environmental indicators have been integrated into the management planning of national parks, playing a crucial role in evaluating their effectiveness [15].

From a sustainability perspective, and particularly in relation to land-use-related human activities that can generate environmental impacts, the 1993 UNESCO program's emphasis on a shift in urban indicator conception is noteworthy [16]. This shift promotes an ecological interpretation of indicators, enabling the evaluation of material and energy flows, interactions between urban and environmental systems, and the interrelationships between economy, ecology, and urban policy [17].

Consequently, a significant portion of land use indicators established for cities and municipalities aim to serve as a cornerstone tool for evaluating and monitoring local sustainability in relation to land use patterns. From an ecological urban planning perspective, these indicators champion a compact city model. This model prioritizes reduced land consumption, maximizes efficiency in natural resource utilization, and minimizes the pressure exerted by urban systems on supporting ecosystems [18–25]. The increased use of environmental indices and indicators based on land use and land cover for assessing the sustainability of national parks and areas of high environmental value can be partly attributed to the capabilities offered by GIS tools (such as ArcGIS Pro v2.9, which was used in this study) and official databases [18–25].

Land use changes in the Doñana area, a socio-ecological system with unique characteristics and significant societal services (agriculture being particularly prominent) [3,5,26], represent a key human-induced factor driving territorial transformation. This area has faced a decades-long struggle to balance conservation of its environmental values with fostering economic development for a historically disadvantaged region. Land occupation, reflecting a region's development model, becomes a crucial indicator for understanding sustainability dynamics in Doñana. Here, the territory grapples with a matrix of land uses associated with expanding intensive agriculture, tourism, and urbanization projects [27].

Therefore, the inclusion of an environmental value index like the WEI in this sustainability analysis is inherently justified. By applying this analysis to a space as significant as Doñana, the spatial and temporal evaluation of WEI will provide valuable information for investigating the area's sustainability.

2. Materials and Methods

2.1. The Doñana Area and the Municipalities under Study

Doñana, a unique territorial area of 2733 km^2, occupies the southwestern tip of the Iberian Peninsula. Its physical boundaries are the Guadalquivir River (lower course towards its mouth) to the east, the A-49 highway connecting Seville and Huelva to the north, the Tinto River to the northwest, and the Atlantic Ocean along the entire coastal strip between the mouths of the Guadalquivir and Tinto rivers to the southwest [28].

Encompassing municipalities across two provinces, Doñana's territorial management plan includes Almonte, Bonares, Bollullos Par del Condado, Hinojos, Lucena del Puerto, Moguer, Palos de la Frontera, and Rociana del Condado in the Province of Huelva, and Aznalcázar, Isla Mayor, La Puebla del Río, Pilas, and Villamanrique de la Condesa in the Province of Seville (Figure 1).

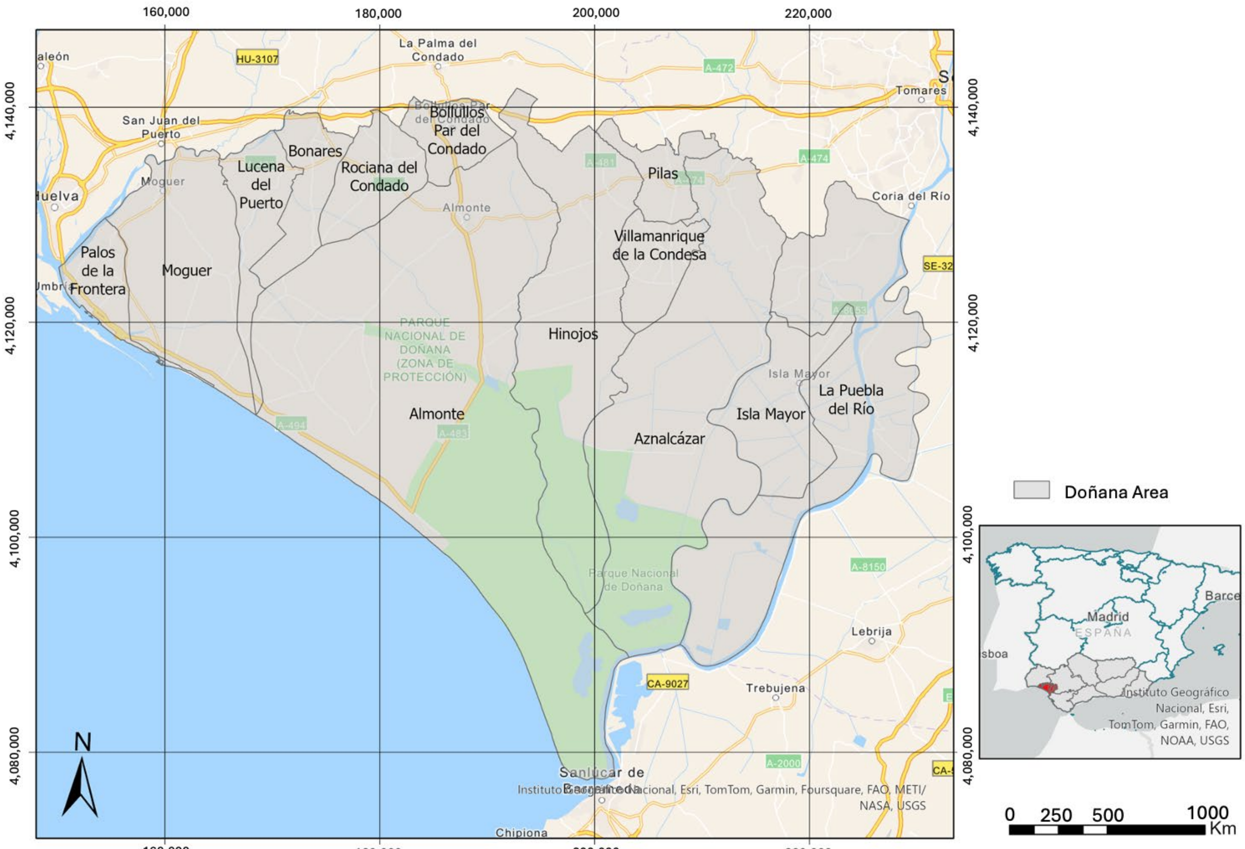

Figure 1. Location of the municipalities around the Doñana area.

The A-49 highway serves as a crucial element for the Doñana area, functioning as a northern boundary, a transportation link, and a structuring axis. The region's entire urban system has developed around this corridor, with urban, agricultural, industrial, and infrastructure uses concentrated in its vicinity [29].

South of the A-49 lies a vast expanse with distinct characteristics. This territory is marked by demographic sparsity and a dominance of interactions between the biophysical substrate (the underlying geological and biological foundation) and natural resource utilization [29]. This southern region encompasses the most ecologically and environmentally valuable spaces within Doñana, including the Doñana Natural Space, which incorporates both the Natural and National Parks. All known planning instruments in the area have been developed with the protection of these high-value ecosystems as a primary objective. Table 1 presents the key characteristics of the municipalities included in this study.

Table 1. Characteristics of the municipalities under study [30].

Municipality	Area (km^2)	Perimeter (km)	Distance to Seville (km)	Altitude (m.o.s.l.)	Population in 2023	Population Centers	Protected Natural Spaces (%)
Almonte	860.12	163.01	44.9	74	25,233	5	66.76
Bollullos Par del Condado	49.39	31.66	41.9	108	14,263	1	---
Bonares	64.89	48.99	28.7	70	6101	4	23.10
Hinojos	320.34	128.69	58.5	80	4094	1	71.77
Lucena del Puerto	69.86	64.84	24	82	3278	1	20.48
Moguer	204.15	69.34	19.6	49	22,956	4	18.53
Palos de la Frontera	49.12	62.71	12.7	20	12,537	4	16.00
Rociana del Condado	72.07	36.58	36.4	97	8048	1	---
Aznalcázar	450.21	139.58	26.7	65	4820	2	45.03
Isla Mayor	114.51	60.77	40.9	3	5741	2	4.92
La Puebla del Río	375.14	159.03	16.8	20	11,862	2	32.58
Pilas	46	48.13	31.7	66	14,052	1	2.61
Villamanrique de la Condesa	57.74	36.44	36.1	31	4640	1	32.27

2.2. The SIOSE Database and the WEI Index

To address the need for more granular land use information at a national scale, the Spanish Land Occupation Information System (SIOSE) was developed in 2005. SIOSE utilizes an object-oriented conceptual data model, featuring 40 simple classes and 46 compound classes, with a spatial resolution of 1:25,000. Polygons serve as the fundamental unit of information, with minimum mappable surface areas established at 2 hectares for agricultural, forest, and natural areas; 1 hectare for urban areas and water bodies; and 0.5 hectares for crops [31].

The SIOSE conceptual model incorporates two superclasses: land use and land cover. Land cover can be either simple (one type per polygon) or composite (multiple simple or composite cover types within a single polygon). In contrast, land use refers to the socioeconomic activity associated with an area and may not directly correspond to a physical characteristic. For instance, a forest cover could have various land use types [31]. Therefore, the SIOSE model allows for assigning one or more simple or composite coverages to a single polygon through its attributes and occupancy percentages, rather than defining a single coverage for each polygon. This approach enables SIOSE to provide more detailed and user-specific land use information [32].

This study employs the Weighted Environmental Index (WEI) [9,10], a recently developed index for analyzing environmental value based on land use. The WEI facilitates the quantification of a specific area's environmental value by considering its land use characteristics. This index is particularly advantageous for land use assessments that leverage data integrated within Geographic Information Systems. The WEI's scalability allows for its application at both local and regional levels, enabling detailed studies using high-resolution GIS data. Furthermore, applying the WEI to the same geographical area at different points in time facilitates trend analysis, which can be used to evaluate the effectiveness of corrective measures implemented through territorial, urban, or environmental planning instruments.

As described in [9,10], the assessment of the WEI index involves quantifying the environmental index (EIj) values for each land use. This has been accomplished by considering the combined influence of the following five evaluation factors (Fi):

F1: Anthropic or natural nature of activity developed in soil.
F2: Water consumption associated with land use.
F3: Soil degradation (use of chemicals).
F4: Environmental sustainability of land use (stability of the ecosystem).
F5: Landscape value of activity carried out in the analyzed area.

The determination of values of the evaluation factors for each land use is carried out individually so that a quantitative value is assigned for each factor F_i and land use j, in such a way that

$$0 \leq F_{ij} \leq 100 \tag{1}$$

For each of the land use categories included in the SIOSE legend, the corresponding environmental index (EIj) has been derived as the weighted average of the values assigned to each of the preceding factors (Fi), taking into account the respective weights (α_i), as illustrated in Equations (2) and (3):

$$EI_j = \sum_{i=1}^{5} \alpha_i F_{ij} \qquad i = 1 \ldots 5 \; j = 1 \ldots ncat \tag{2}$$

$$\sum_{i=1}^{5} \alpha_i = 1 \tag{3}$$

where

EI_j: environmental index of land use j ($0 \leq E_{ij} \leq 100$).
α_i : assigned weights to factor i.
F_i: evaluation factor i.
ncat: land use categories.

The application of EI_j is conducted through discretization into irregular polygons of variable surface, collectively constituting the entire area under study.

$$A_{total} = \sum_{k=1}^{npol} A_k \tag{4}$$

where

A_{total}: total area of study.
A_k: area of polygon k.
npol: total number of polygons in the discretization.

Therefore, when utilizing the SIOSE database, after establishing the environmental index values corresponding to each land use, the weighted environmental index of a specific polygon (WEI_k) is determined based on the environmental index values of each land use contained within the polygon. This calculation considers the proportions of the area assigned to each land use relative to the total area of the polygon, serving as weights, as shown in Equation (6).

$$\beta_{jk} = \frac{A_{jk}}{A_k} \quad k = 1 \ldots npol \tag{5}$$

$$WEI_k = \sum_{j=1}^{n_{jk}} \beta_{jk} EI_j \quad j = 1 \ldots n_{jk} \tag{6}$$

where

WEI_k: weighted environmental index of polygon k.
EI_j: environmental index of land use j.
A_{jk}: area assigned to land use j inside the polygon k.
β_{jk}: land use weighting factor j in polygon k.
njk: number of land uses (j) inside polygon k.

The value of the weighted environmental index obtained through Equation (6) ranges between 0 and 100, where values closer to 0 indicate a very low environmental value, while values closer to 100 indicate a high environmental value. This aligns with the five evaluation factors (F_i) considered in defining the environmental index for each type of land use.

Thus, WEI_k values are derived from EI_j values, which are contingent upon the values assigned to the evaluation factors (F_i) and the weights associated with each factor (α_i). Consequently, the value of the WEI index hinges on the corresponding values of the evaluation factors (F_i) and their respective weights (α_i). The values of F_i and α_i should be determined by the modeler based on expert knowledge, taking into account local advice.

The application of the WEI to each land use category identified by any land use legend enables classification based on the discrimination by ranges outlined in Table 2.

Table 2. Environmental value as a function of the WEI range.

WEI Range	Environmental Value
$0 \leq WEI_k < 40$	Low
$40 \leq WEI_k < 70$	Medium
$70 \leq WEI_k \leq 100$	High

2.3. The Map of Land Uses and Vegetation Cover in Andalusia (MUCVA)

The Map of Land Uses and Vegetation Cover in Andalusia (MUCVA) is a robust and flexible data model offering an accurate and detailed representation of Andalusia's land surface. Initiated in 1987 by the Andalusian Department of Environment, this project coincided with the European Union's CORINE-Land Cover Program [33], which produced the national land use map for Spain as part of a Europe-wide land use mapping initiative. MUCVA was initially developed at a scale of 1:100,000. Data from MUCVA are accessible through the Andalusian Regional Government's Environmental Information Network platform (REDIAM) [11].

A significant improvement for regional applications came in 1991 with the introduction of the first Andalusian land use map at a 1:50,000 scale. Advancements in information technology and the availability of higher-quality remote sensing products, such as satellite imagery and digital elevation models, have facilitated the development of increasingly detailed and precise cartographic products tailored to regional needs. Currently, vegetation cover maps for Andalusia are available at a 1:50,000 scale for the years 1991, 1995, and 1999 (first version).

As information is updated, particularly through comprehensive photogrammetric flights of the entire region, a cartographic update methodology has been developed to ensure the continuous improvement of map quality. This methodology has facilitated the generation of a second version of the 1999 map, alongside updated maps for 2003 and 2007. The MUCVA has continuously adapted over time to meet environmental management needs and reflect the specific characteristics of Andalusia.

The MUCVA data model is based on the initial structure of the CORINE Land Cover project. This model offers a high level of disaggregation, comprising 112 classes categorized into four main groups: built-up areas and infrastructures, wetlands and water surfaces, agricultural territories, and forest and natural areas. These main groups branch out further into 12 subgroups, 41 classes, 67 subclasses, 31 types, and 7 subtypes, providing increasingly granular detail.

A noteworthy feature of the current MUCVA model is the integration of taxonomic information within the forest and natural areas group. This enriches the map's content significantly by incorporating details on plant species and vegetation formations, crucial for environmental management and conservation efforts [34]. The inclusion of such data provides finer resolution on the natural vegetation cover, enabling more precise calculations of the WEI index. This ultimately contributes to a more accurate assessment of the environmental state and informed decision making regarding natural resource management in Andalusia.

This study utilizes MUCVA data for 1991 and 1999, complemented by SIOSE data for 2016. While comparative studies between SIOSE and MUCVA are limited, methods have been proposed to convert the object-oriented SIOSE model into a hierarchical structure resembling MUCVA [35]. The Andalusian Department of Environment has undertaken efforts to quantify regional-level discrepancies, identifying an overestimation of built-up areas and an underestimation of agricultural areas in SIOSE. These discrepancies can be primarily attributed to the inherent structural differences of the models, along with variations in nomenclature and spatial element geometries [35]. Nevertheless, the priority of providing comprehensive and up-to-date land use information at the national level necessitates the use of SIOSE data for the year 2016.

Figure 2a,b displays the land uses in the study area using the legend provided by MUCVA in 1991 and 2016, respectively.

2.4. Adaptation of the WEI Index to the MUCVA Database

Table 3 presents the assigned values for the Weighted Environmental Index (WEI_k) for each land use category as defined by the MUCVA legend. These WEI_k values were determined by comparing the MUCVA and SIOSE database legends. Since SIOSE land use values are predefined [9], equivalences were established between the two databases, considering prior efforts to achieve standardization [35]. For land use categories lacking clear correspondences between MUCVA and SIOSE, the corresponding values for each environmental factor (Fi) were defined manually.

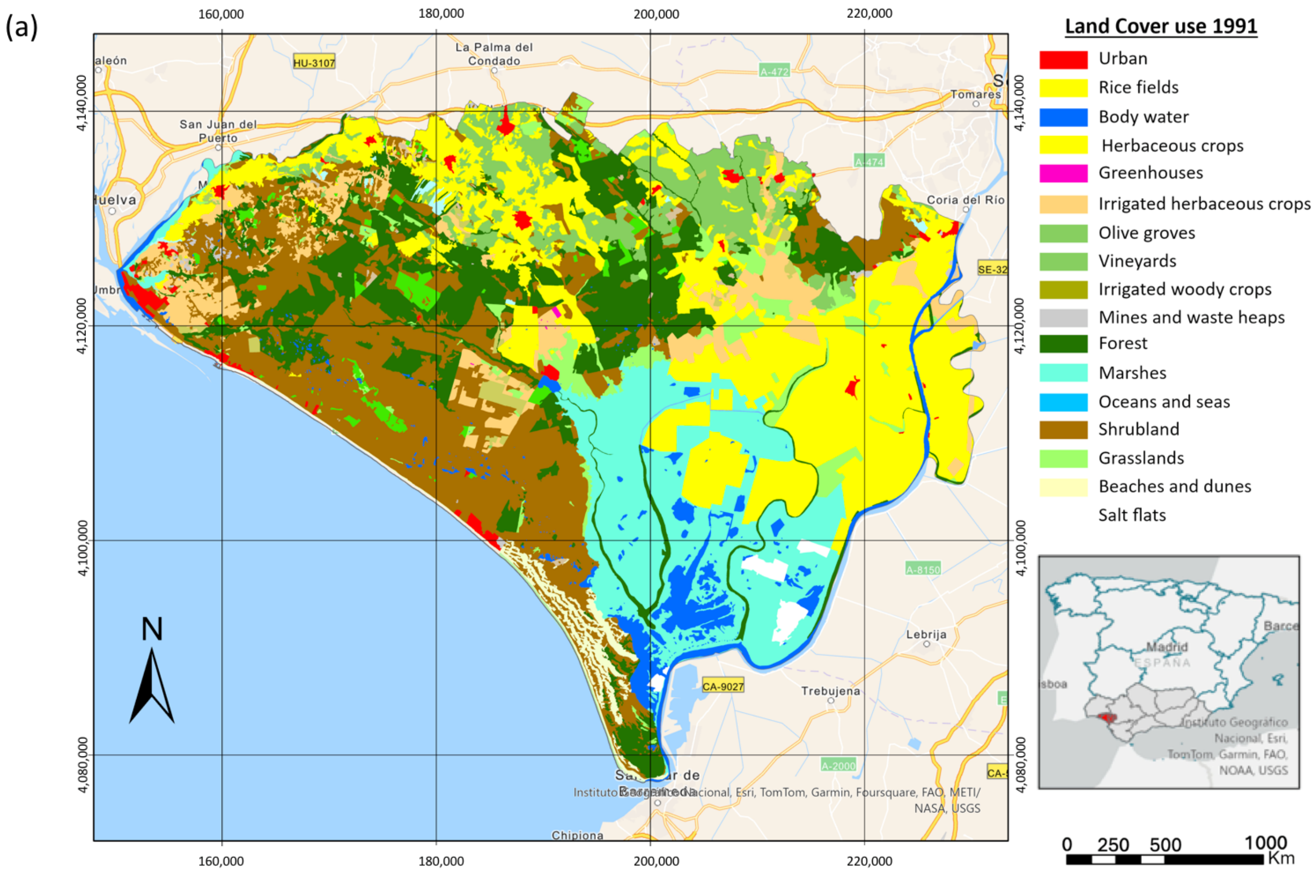

Figure 2. *Cont.*

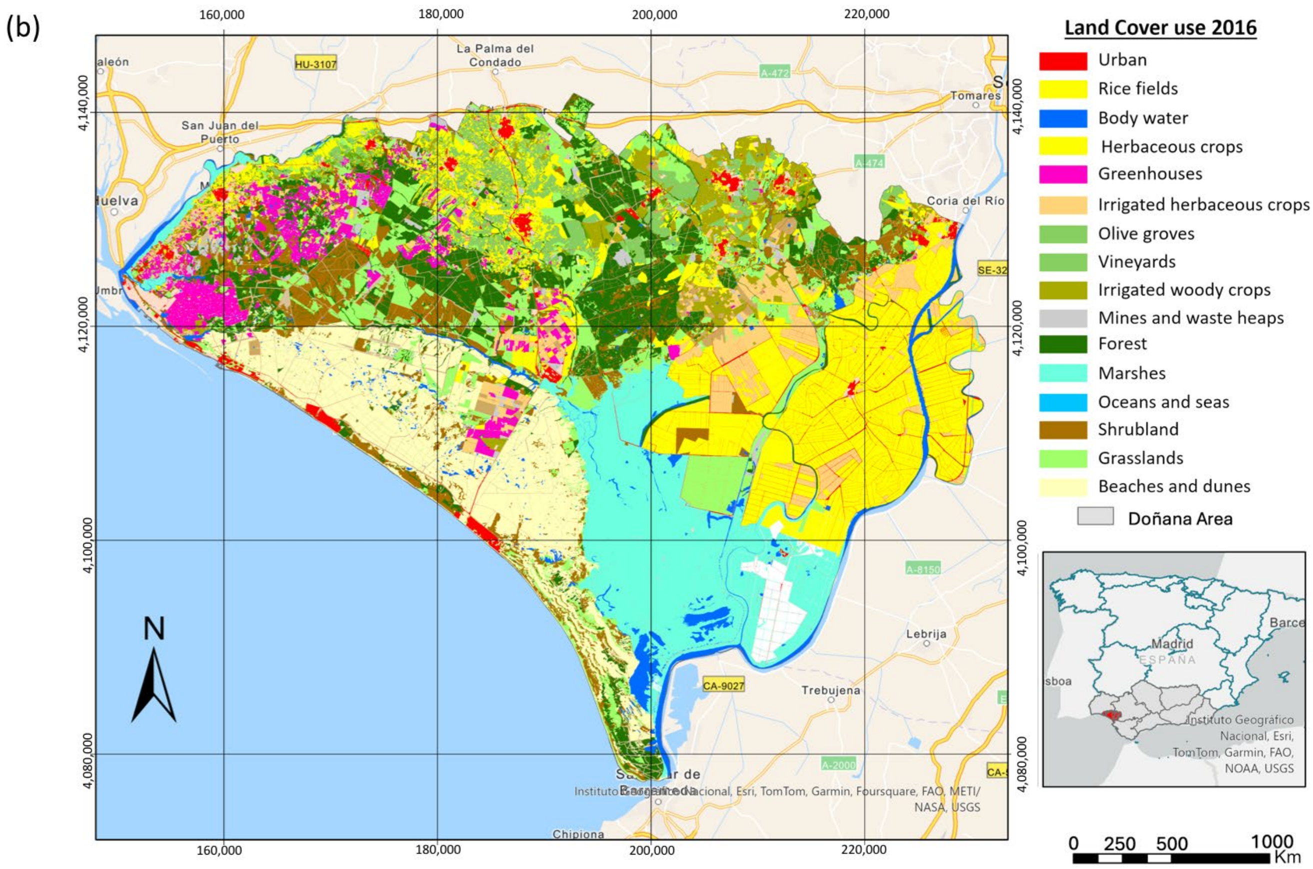

Figure 2. Land use on the municipalities around the Doñana area for (**a**) 1991, and (**b**) 2016.

Table 3. Values of the evaluation factors (F_i) for every land use considered by the SIOSE and the MUCVA databases and final value of the WEI Index for each single-use polygon (WEI_k).

MUCVA Code	Land Use Description	F_1	F_2	F_3	F_4	F_5	WEI_k
111	Urban fabric	20	20	20	20	20	20
115	Residential developments	30	30	10	20	10	20
117	Agricultural/residential developments	40	50	60	50	50	50
121	Industrial and commercial areas	20	20	20	20	20	20
131	Highways, motorways, and road links	20	40	20	15	5	20
133	Railway complexes	10	10	10	10	10	10
135	Port areas	10	10	10	10	10	10
137	Airports	10	10	10	10	10	10
141	Other technical infrastructures	10	10	10	10	10	10
151	Mining areas	10	10	10	10	10	10
153	Spoil tips and landfills	0	0	0	0	0	0
155	Construction zones	35	50	50	50	15	40
157	Olive oil waste sludge reservoirs	0	0	0	0	0	0
191	Urban green areas	60	65	70	80	75	70
193	Sports and recreational facilities	35	35	35	35	35	35
211	Tidal marshes with vegetation	80	50	30	80	60	60
215	Non-tidal marshes with vegetation	80	50	30	80	60	60
217	Recent non-vegetated marshes	80	50	30	80	60	60
221	Traditional saltworks	90	30	40	80	60	60
225	Industrial saltworks and crop parks	90	30	40	80	60	60
241	Estuaries and tidal channels	80	50	30	80	60	60
291	Seas and oceans	100	100	100	100	100	100
311	Natural rivers and channels: water surface	100	100	100	100	100	100

Table 3. *Cont.*

MUCVA Code	Land Use Description	F_1	F_2	F_3	F_4	F_5	WEI_k
315	Natural rivers and channels: riparian forest	100	100	100	100	100	100
317	Natural rivers and channels: other riparian formations	100	100	100	100	100	100
321	Artificial channels	0	0	0	0	0	0
331	Continental lagoons	100	100	100	100	100	100
341	Reservoirs: water surface	10	100	100	100	90	80
345	Irrigation and livestock reservoirs	10	100	100	100	90	80
411	Dryland herbaceous crops	60	65	40	50	50	53
411	Irrigated herbaceous crops	60	65	40	50	50	53
415	Dryland woody crops: olive groves	60	65	80	75	70	70
415	Irrigated woody crops: olive trees	60	65	80	75	70	70
417	Dryland woody crops: vineyards	60	65	80	75	70	70
417	Irrigated woody crops: vineyards	60	65	80	75	70	70
419	Other dryland woody crops	60	65	80	75	70	70
421	Rice fields	60	10	80	45	55	50
423	Forced crops under plastic	10	40	40	40	20	30
425	Other irrigated herbaceous crops	60	65	80	75	70	70
427	Herbaceous crops under irrigation: irrigated and non-irrigated	60	65	80	75	70	70
429	Herbaceous crops under irrigation: non-irrigated	60	65	80	75	70	70
430	Woody crops under irrigation: partially irrigated or non-irrigated	60	65	80	75	70	70
431	Irrigated woody crops: citrus	60	65	80	75	70	70
433	Irrigated woody crops: olive trees	60	65	80	75	70	70
439	Other irrigated woody crops	60	65	80	75	70	70
441	Herbaceous and woody crops in dryland	60	37	80	60	62	60
445	Olive grove-vineyard	60	65	80	75	70	70
449	Other associations and mosaics of dryland woody crops	60	65	80	75	70	70
451	Herbaceous and woody crops under irrigation	60	65	60	75	70	66
455	Herbaceous and woody crops under partial irrigation	60	60	60	60	60	60
457	Herbaceous and woody crops under non-irrigation	65	65	65	65	65	65
459	Mosaic of woody crops under irrigation	70	70	70	70	70	70
461	Mosaic of dryland and irrigated land with herbaceous crops	60	51	80	67	66	65
465	Mosaic of dry and irrigated land with herbaceous + woody crops	47	59	70	66	57	60
469	Mosaic of dryland and irrigated land with woody crops	60	65	80	75	70	70
471	Herbaceous crops and pastures	60	60	60	60	60	60
473	Herbaceous crops and natural woody vegetation	70	75	60	65	65	67
475	Woody crops and pastures	70	70	70	70	70	70
477	Woody crops and natural woody vegetation	80	80	80	75	75	78
479	Other mosaics of crops and natural vegetation	75	75	75	72	72	74
481	Abandoned olive groves	60	65	80	75	80	72
510	Dense wooded formations: oaks	100	100	100	100	100	100
520	Dense wooded formations: conifers	100	100	100	100	100	100
530	Dense wooded formations: eucalyptus	80	70	100	100	100	90
540	Dense wooded formations: other broadleaf species	100	100	100	100	100	100
550	Dense wooded formations: oaks + conifers	100	100	100	100	100	100
560	Dense wooded formations: oaks + eucalyptus	90	85	100	100	100	95
570	Dense wooded formations: conifers + eucalyptus	90	85	100	100	100	95
580	Dense wooded formations: other mixtures	100	100	100	100	100	100
611	Dense shrub with trees: dense oaks	100	100	100	100	100	100
615	Dense shrub with trees: scattered oaks	100	100	100	100	100	100
621	Dense shrub with trees: dense conifers	100	100	100	100	100	100
625	Dense shrub with trees: scattered conifers	100	100	100	100	100	100
630	Dense shrub with trees: eucalyptus	90	85	100	100	100	95
640	Dense shrub with trees: other broadleaf species	100	100	100	100	100	100
650	Dense shrub with trees: oaks + conifers	100	100	100	100	100	100
660	Dense shrub with trees: oaks + eucalyptus	80	70	100	100	100	90
670	Dense shrub with trees: conifers + eucalyptus	90	85	100	100	100	95

Table 3. *Cont.*

MUCVA Code	Land Use Description	F_1	F_2	F_3	F_4	F_5	WEI_k
680	Dense shrub with trees: other mixtures	100	100	100	100	100	100
711	Scattered shrub with trees: oaks. Dense	100	100	100	100	100	100
715	Scattered shrub with trees: oaks. Scattered	100	100	100	100	100	100
721	Scattered shrub with trees: conifers. Dense	100	100	100	100	100	100
725	Scattered shrub with trees: conifers. Scattered	100	100	100	100	100	100
730	Scattered shrub with trees: eucalyptus	90	85	100	100	100	95
740	Scattered shrub with trees: other broadleaf species	100	100	100	100	100	100
750	Scattered shrub with trees: oaks + conifers	100	100	100	100	100	100
760	Scattered shrub with trees: oaks + eucalyptus	80	70	100	100	100	90
770	Scattered shrub with trees: conifers + eucalyptus	90	85	100	100	100	95
780	Scattered shrub with trees: other mixtures	100	100	100	100	100	100
811	Woody pasture: oaks. Dense	100	100	100	100	100	100
815	Woody pasture: oaks. Scattered	100	100	100	100	100	100
821	Woody pasture: conifers. Dense	100	100	100	100	100	100
825	Woody pasture: conifers. Scattered	100	100	100	100	100	100
830	Woody pasture: eucalyptus	90	85	100	100	100	95
840	Woody pasture: other broadleaf species	100	100	100	100	100	100
850	Woody pasture: oaks + conifers	100	100	100	100	100	100
860	Woody pasture: oaks + eucalyptus	90	85	100	100	100	95
870	Woody pasture: conifers + eucalyptus	80	70	100	100	100	90
880	Woody pasture: other mixtures	100	100	100	100	100	100
891	Herbaceous crops with trees: oaks. Dense	100	100	100	100	100	100
895	Herbaceous crops with trees: oaks. Scattered	100	100	100	100	100	100
901	Recent forest clearings and plantations	90	90	100	100	85	93
911	Dense shrub	70	70	70	70	70	70
915	Scattered shrub with pastures	75	75	75	75	75	75
917	Scattered shrub with grass and rock or soil	70	70	70	70	70	70
921	Continuous pasture	80	80	80	80	80	80
925	Pasture with clearings (rock, soil)	70	70	70	70	70	70
931	Beaches, dunes, and sands	100	100	50	100	100	90
932	Rocks and bare soil	40	40	40	40	40	40
933	Areas with strong erosion processes	30	30	30	30	30	30
935	Areas without vegetation due to cultivation	70	50	20	20	40	40

As detailed in this paper, the values presented in Table 3 for each environmental factor (Fi) are specific to the Doñana area study. For this research, all factors were assigned equal weights ($\alpha_i = 0.2$).

3. Results

The Weighted Environmental Index (WEI) was employed to analyze the evolution of the environmental status of the Doñana area between 1991 and 2016. This analysis encompassed the park's zone of influence, which includes the 13 municipalities described earlier and covers a total area of 2734 km^2. The results obtained from applying the WEI index is presented and discussed below.

As stated above, the data used for these studies were downloaded from the Environmental Information Network platform of Andalusia (REDIAM) of the Regional Government of Andalusia [11]. These data included MUCVA information available for Andalusia in 1991, 1999, and SIOSE 2016. In order to compare land uses between both databases, the land use legend of SIOSE 2016 was standardized to the legend of MUCVA 1991 and 1999, using the proposed standardization available on the REDIAM website.

The land use and vegetation cover data for this study adhere to the ETR89 geodetic reference system and the Universal Transverse Mercator (UTM) projection system in zone 30. These data are collaboratively developed and updated through the SIOSE/SIPNA project (Land Use Information System and Natural Heritage Information System of Andalusia) [11]. High-resolution satellite imagery served as the primary temporal reference for the analysis. This imagery allowed for the observation of land use pattern changes over time by providing a broad perspective encompassing large areas within the territory of interest. Additionally, it facilitated the detection of temporal variations, including seasonal changes and long-term land use trends.

Satellite imagery was complemented by high-resolution aerial orthophotos. These orthophotos are geometrically corrected to account for distortions caused by Earth's curvature and camera angle. They provided a precise geometric reference for accurate distance and area measurements of territorial features. The combined use of satellite imagery and orthophotos ensured comprehensive and reliable data on land uses and vegetation cover.

Understanding the evolution of the WEI over time necessitates examining land use changes within the Doñana area. A comprehensive Excel spreadsheet detailing the surface areas associated with each land use category in the Doñana municipalities between 1991 and 2016 is provided in the Supplementary Materials.

Table 4 highlights the eight land use categories that have undergone the most significant surface area modifications during the 1991–2016 period. Here, we delve into a detailed analysis of the land use exhibiting the most substantial increase from 1991 to 2016.

Table 4. Most relevant land use changes between 1991 and 2016.

MUCVA Code	Land Use Description	WEI_k	Area 1991 (Has)	% Over Total Area	Area 2016 (Has)	% Over Total Area	Δ Area (1991–2016)
211	Tidal marshes with vegetation	60	1325.94	0.49%	33,604.62	12.31%	32,278.68
931	Beaches, dunes, and sands	90	3959.00	1.46%	32,354.41	11.85%	28,395.41
411	Irrigated herbaceous crops	53		0.00%	12,551.25	4.60%	12,551.25
423	Forced crops under plastic	30	62.29	0.02%	9378.08	3.43%	9315.80
415	Irrigated woody crops: olive trees	70		0.00%	5484.61	2.01%	5484.61
935	Areas without vegetation due to cultivation	40	605.48	0.22%	5197.74	1.90%	4592.25
825	Woody pasture: conifers. Scattered	100	147.62	0.05%	4732.43	1.73%	4584.81

"Tidal marshes with vegetation" (MUCVA code: 211) exemplifies a land use category with a notable area increase. In 1991, this land use covered 1325.94 hectares, constituting only 0.49% of the total study area. By 2016, this area had grown significantly to 33,604.62 hectares, representing 12.31% of the total area. Since "tidal marshes with vegetation" carries a moderate WEI value (WEI_k = 60), this substantial increase is likely to have a significant impact on the overall WEI of the study area. Similar analyses can be conducted for the remaining land use categories present within the region.

Spatial data analysis techniques were employed to evaluate the WEI across the Doñana area. This involved querying the MUCVA data model for each polygon within the study area for the years 1991, 1999, and 2016. The query results provided information on land cover type, surface area, and percentage of occupation within each polygon.

This information formed the basis for WEI analysis. The WEI values were then linked to the corresponding GIS polygon identifiers, enabling spatial representation of the index's evolution across the three years. For consistency, the evaluation factor values (F_i) and weights (α_i) were maintained throughout the analyses. The specific evaluation factors used (as shown in Table 3) were chosen through expert judgment, with all factors assigned equal weight.

Figure 3 shows the spatial distribution of the WEI across the Doñana area for 1991, 1999, and 2016. As expected, areas with the lowest WEI values tend to cluster around cities and villages, particularly in the western portion of the study area. This observation aligns with the understanding that urbanization typically leads to a decrease in environmental value due to factors like reduced natural land cover and increased resource consumption.

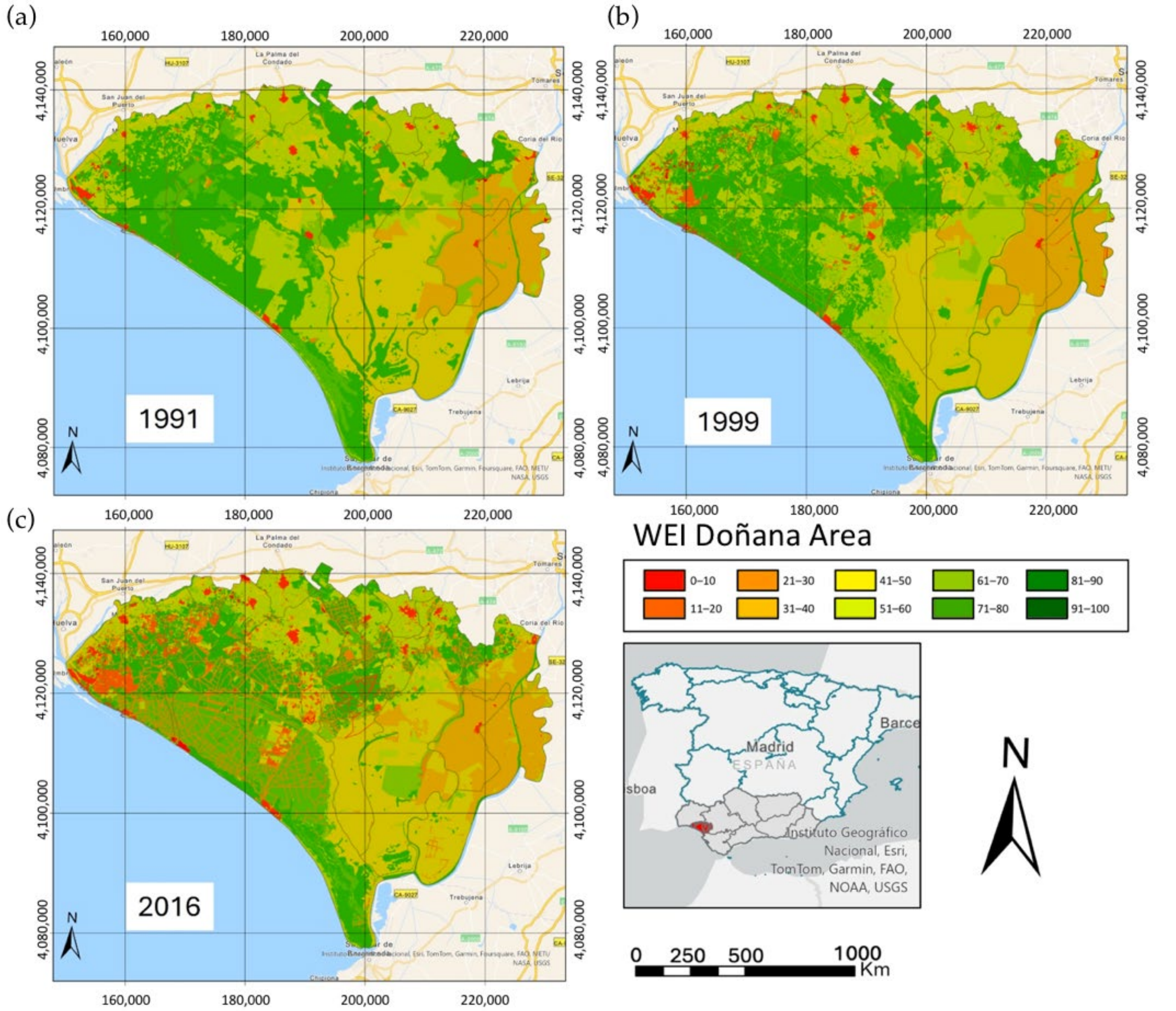

Figure 3. WEI values in the municipalities around the Doñana area in (**a**) 1991, (**b**) 1999, and (**c**) 2016.

The successful application of the WEI to analyze the environmental status of the municipalities of Doñana area highlights its potential as a valuable tool for regional environmental assessments. This reinforces the notion that the WEI can be effectively utilized for such purposes, provided there is access to sufficient and accurate land cover data.

Figure 4 illustrates the spatial distribution of WEI changes across the study area between 1991 and 2016. Green areas represent locations where the WEI has increased, indicating an improvement in environmental value. Conversely, red areas represent areas where the WEI has decreased, signifying a decline in environmental value. This figure allows for the efficient identification of zones that have experienced either improvement or degradation in their environmental state during each analyzed period.

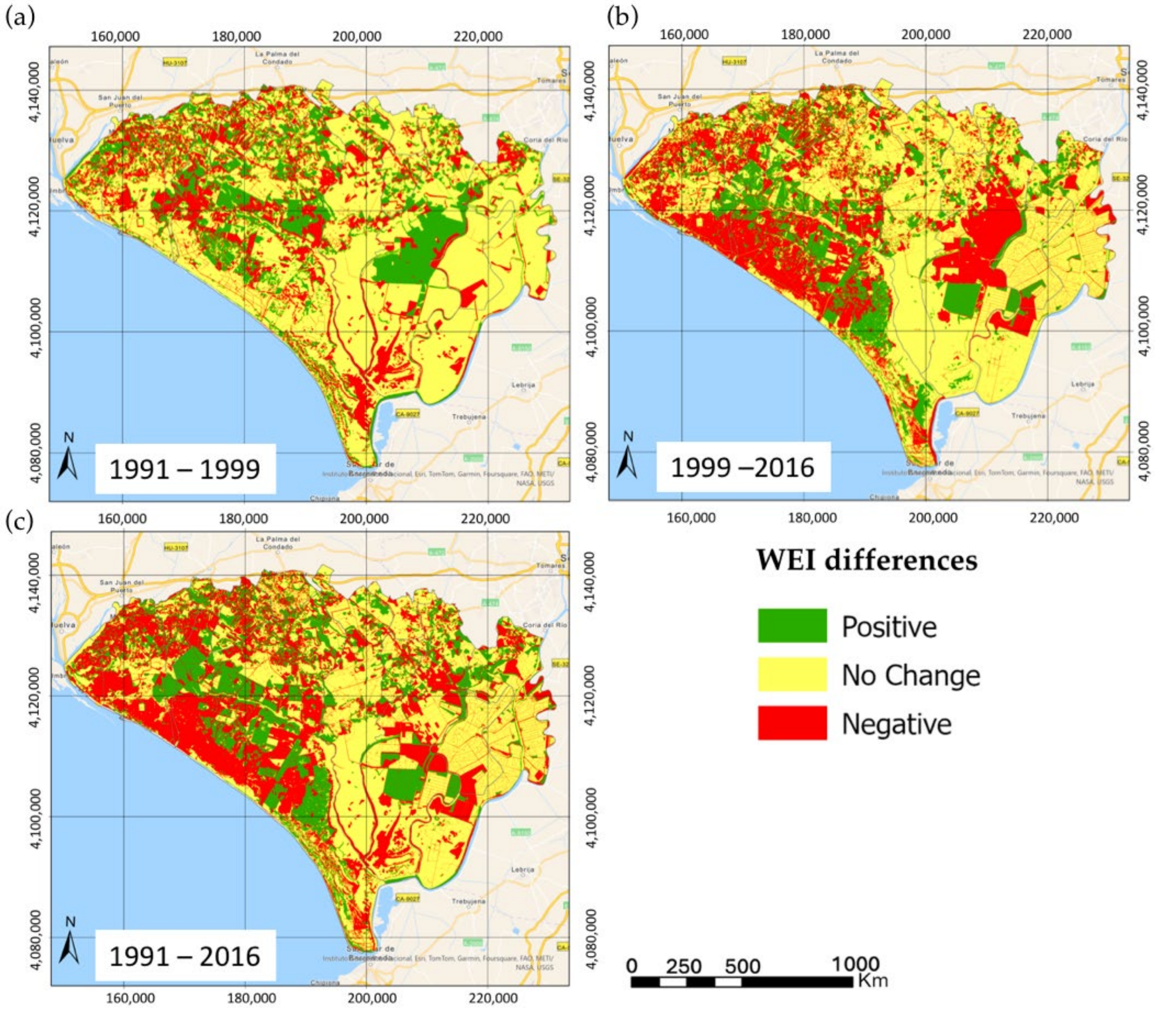

Figure 4. WEI differences on the study period. (**a**) Differences between 1991 and 1999, (**b**) differences between 1999 and 2016, and (**c**) differences between 1991 and 2016.

The results in Figure 4 reveal the most significant WEI variations occurring between 1999 and 2016. These variations are scattered throughout the study area, with a concentration near the coast and even within Doñana National Park itself.

Figure 5 presents the evolution of the average WEI for the municipalities of the Doñana area between 1991 and 2016. The average WEI was calculated as the area-weighted average of the WEI values within each polygon across the study area.

An examination of Figure 5 reveals a concerning trend of declining environmental value. In 1991, the average WEI stood at 74.48. By 1999, this value had decreased to 73.36, representing a loss of 1.51% over an eight-year period. This decline continued between 1999 and 2016, with the WEI value dropping to 69.41. Consequently, the overall WEI for the 1991–2016 period reflects a decrease of 6.81%.

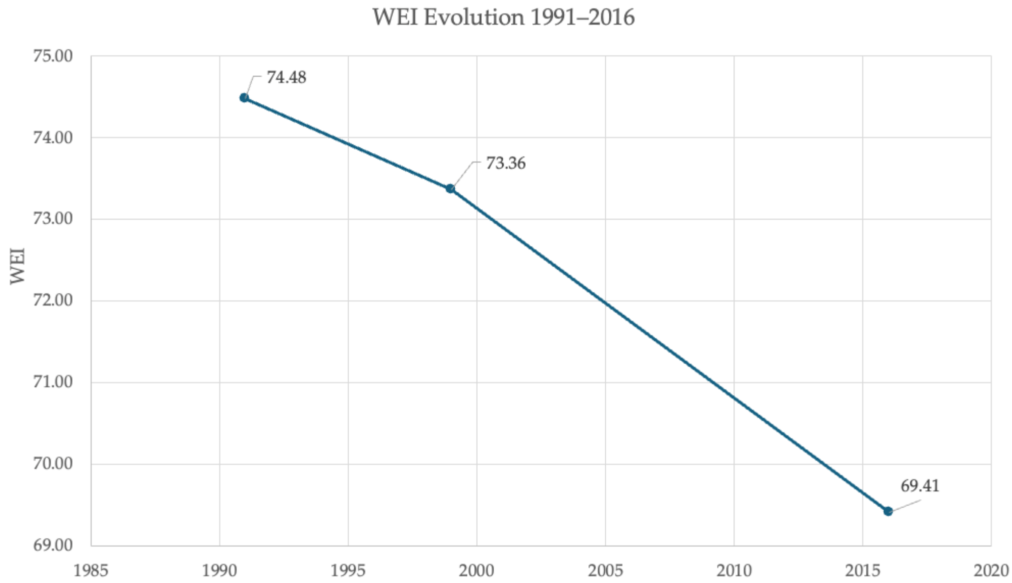

Figure 5. Average WEI evolution over time in the municipalities around the Doñana area (1991, 1999, and 2016).

This significant decline in the average WEI underscores the urgency of implementing environmental protection policies to reverse this negative trend and ensure the long-term sustainability of the Doñana area's environment.

Data provided by MUCVA allow for a comprehensive analysis of WEI evolution over time. By leveraging this object-oriented database, the study area was subdivided into polygons, with the number increasing significantly from 2673 in 1991 to 12,894 in 1999 and reaching 69,916 in 2016. Examining the statistical distribution of WEI values across these polygons provides valuable insights into environmental status changes between 1991 and 2016.

Table 5 presents the decile values of the WEI distribution functions for each analyzed year. These values are further explored in Figure 6, which visually represents the corresponding cumulative distribution functions (CDFs).

Table 5. Deciles of the WEI distribution function in the municipalities around the Doñana area (1991, 1999, and 2016).

WEI	Class Area (Has)			Class Area (%)			Cumulative (%)		
	1991	1999	2016	1991	1999	2016	1991	1999	2016
[0, 10[	301.96	241.07	69.51	0.11%	0.09%	0.03%	0.11%	0.09%	0.03%
[10, 20[	588.41	643.89	5024.34	0.22%	0.24%	1.84%	0.33%	0.33%	1.87%
[20, 30[	2950.19	3208.21	2026.17	1.08%	1.17%	2.97%	1.41%	1.50%	4.84%
[30, 40[	138.00	2863.90	9749.80	0.05%	1.05%	3.57%	1.46%	2.55%	8.41%
[40, 50[	714.98	2426.38	8298.97	0.26%	0.89%	3.04%	1.72%	3.44%	11.45%
[50, 60[	53,323.94	44,849.97	63,275.27	19.61%	16.41%	23.17%	21.33%	19.85%	34.62%
[60, 70[	52,976.56	54,029.12	38,737.17	19.48%	19.77%	14.19%	40.81%	39.62%	48.81%
[70, 80[	49,259.06	64,199.82	30,177.61	18.11%	23.49%	11.05%	58.92%	63.11%	59.86%
[80, 90[	7026.52	7223.95	8655.91	2.58%	2.64%	3.17%	61.50%	65.75%	63.03%
[90, 100]	104,645.41	93,615.10	100,961.21	38.48%	34.25%	36.97%	100.00%	100.00%	100.00%
Total	271,925.03	273,301.41	266,975.96						

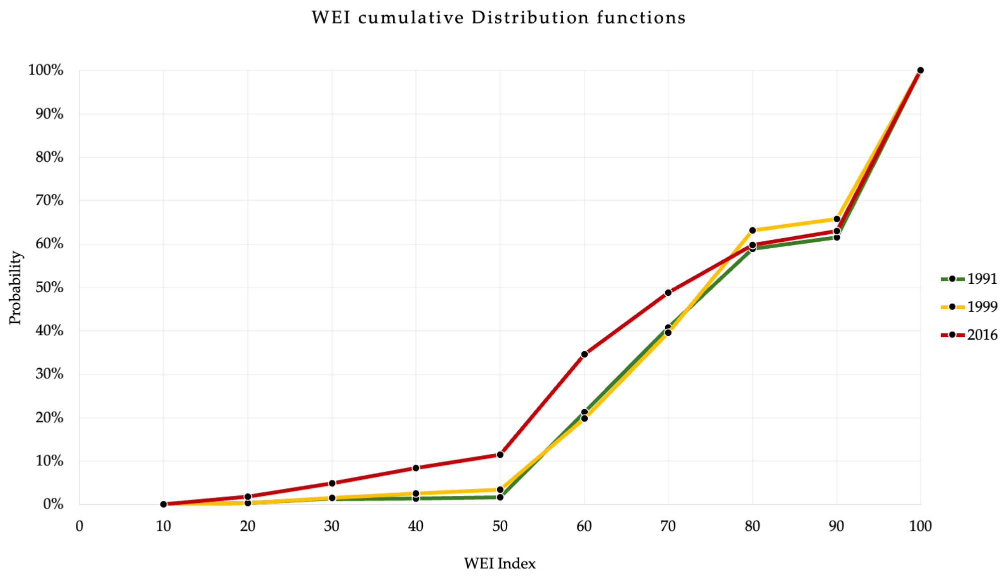

Figure 6. WEI cumulative distribution functions (1991, 1999, and 2016) in the municipalities around the Doñana area.

Figure 6 shows the cumulative distribution functions (CDFs) of the WEI for the years 1991, 1999, and 2016. These CDFs provide valuable insights into the distribution of WEI values across the study area. A notable observation from Figure 6 is the minimal shift in the WEI distribution function between 1991 and 1999. In contrast, a clear leftward shift in the distribution is observed between 1999 and 2016. This shift signifies a general decrease in WEI values across the study area during this latter period.

Table 6 further reinforces this finding by quantifying the changes in land area associated with different WEI classes. In 1999, areas classified as having high environmental value ($70 \leq WEI_k \leq 100$) constituted 60.38% of the total study area. By 2016, this percentage had declined to 51.19%. Conversely, the area classified with low environmental value witnessed a substantial increase, quadrupling from 2.55% in 1999 to 8.41% in 2016.

Table 6. Evolution of the environmental value in the 1991–2016 period.

Environmental Value	WEI Range	1991	1999	2016
Low	$0 \leq WEI_k < 40$	1.46%	2.55%	8.41%
Medium	$40 \leq WEI_k < 70$	39.35%	37.07%	40.40%
High	$70 \leq WEI_k \leq 100$	59.17%	60.38%	51.19%

These observations collectively point towards a concerning trend of environmental degradation within the study area between 1999 and 2016. The decline in high WEI value areas and the concurrent rise in low WEI value areas highlight the urgency for implementing effective environmental protection measures.

The shapes of the CDFs in Figure 6 suggest a trend of decreasing high WEI values, which aligns with the previously observed decline in the average WEI.

As noted earlier, the average WEI surpassed 70 for all years except 2016. This observation is further supported by a comparison of the deciles (WEI values at specific percentiles) across the three years.

Table 7 details these decile values, while Figure 7 presents their graphical representation.

Figure 7a presents a detailed analysis of the decile values derived from the WEI CDF_s for 1991, 1999, and 2016. The y-axis scale is maintained consistent across all three subplots to facilitate direct comparison.

Table 7. WEI cumulative distribution functions' (CDFs) decile differences evolution (1991, 1999, and 2016).

WEI	Class Area (%)			Differences (%)		
	1991	1999	2016	1999–1991	2016–1999	2016–1991
[0, 10[	0.11%	0.09%	0.03%	−0.02%	−0.06%	−0.08%
[10, 20[	0.22%	0.24%	1.84%	0.02%	1.60%	1.62%
[20, 30[	1.08%	1.17%	2.97%	0.09%	1.80%	1.89%
[30, 40[	0.05%	1.05%	3.57%	1.00%	2.52%	3.52%
[40, 50[	0.26%	0.89%	3.04%	0.63%	2.15%	2.78%
[50, 60[	19.61%	16.41%	23.17%	−3.20%	6.76%	3.56%
[60, 70[	19.48%	19.77%	14.19%	0.29%	−5.58%	−5.29%
[70, 80[	18.11%	23.49%	11.05%	5.38%	−12.44%	−7.06%
[80, 90[	2.58%	2.64%	3.17%	0.06%	0.53%	0.59%
[90, 100]	38.48%	34.25%	36.97%	−4.23%	2.72%	−1.51%

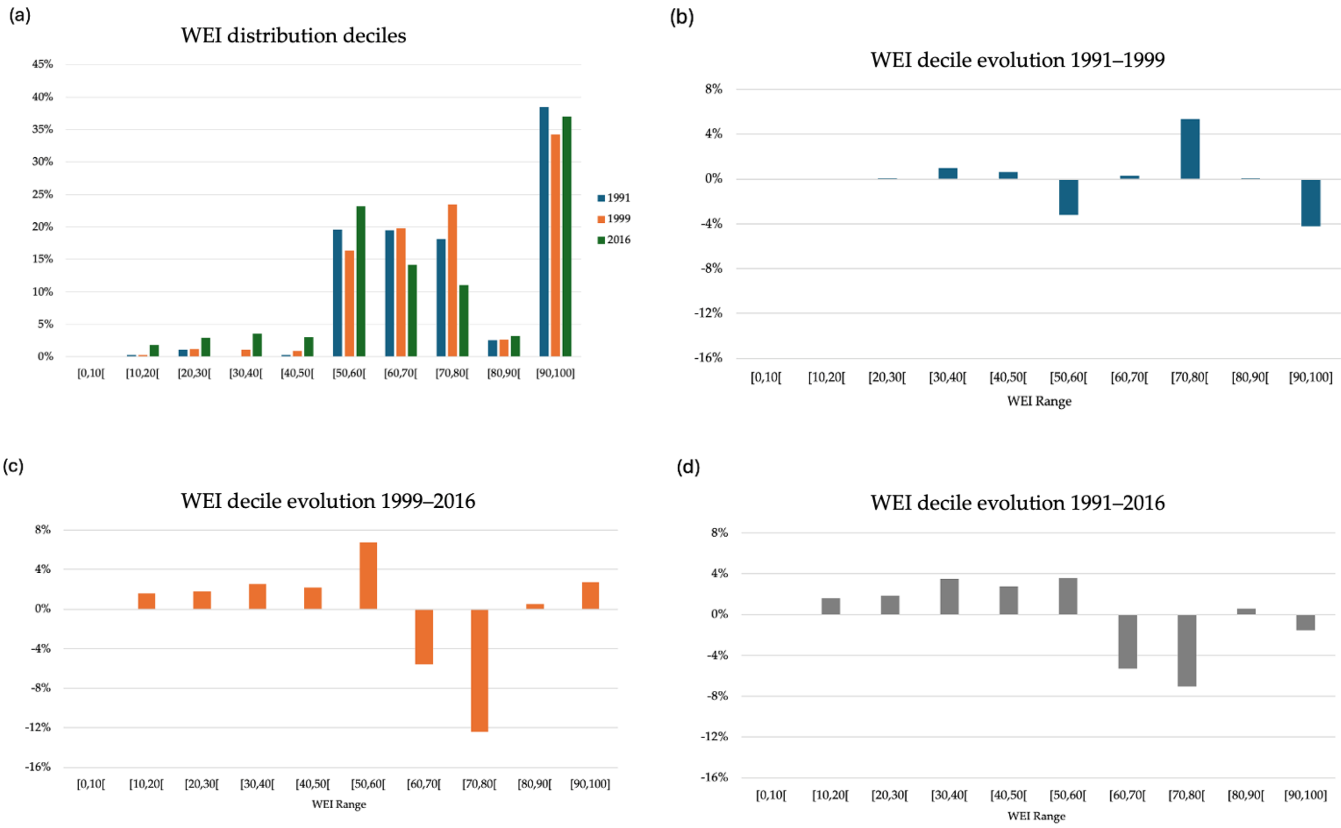

Figure 7. WEI CDF's decile differences evolution. (**a**) Decile values; (**b**) incremental analysis of the CDF's decile evolution between 1991 and 1999; (**c**) incremental analysis of the CDF's decile evolution between 1999 and 2016; (**d**) incremental analysis of the CDF's decile evolution between 1991 and 2016.

As expected, the maximum WEI value (10th decile) for each year fell within the 90–100 WEI range, reflecting the presence of the Doñana National Park within the study area. However, a concerning trend is evident in the decile values corresponding to the 60–80 WEI range. These values show a consistent decrease between 1999 and 2016, indicating a decline in areas with moderate environmental value.

Conversely, the decile values for areas classified with low environmental value (10–60 WEI) exhibited a clear upward trend across all classes during the 1999–2016 period. This observation collectively suggests a concerning shift towards environmental degradation within the study area.

Figure 7b provides a visual representation of the incremental changes in surface area for various WEI classes between 1991 and 1999. While this analysis only considers a single time period, it offers valuable insights into the early trends of environmental change within the study area.

Looking at Figure 7b, we observe a concerning decrease of 4.23% in the surface area classified with the highest environmental value ($90 < WEI_k < 100$) between 1991 and 1999. This decline is partially offset by increases in some mid-range WEI classes. The areas with environmental value between 70 < WEIk < 80 and $40 < WEI_k < 50$ experienced increases of 5.38% and 0.63%, respectively. Additionally, a slight increase of 1.00% is observed for zones classified between $30 < WEI_k < 40$. However, it is important to note that these mid-range gains were not enough to compensate for the substantial loss in the highest WEI class. Overall, this period (1991–1999) appears to show a trend of decreasing area with high environmental value.

Based on these results, we can conclude that between 1991 and 1999, a trend began to emerge, albeit not very pronounced, towards a decrease in environmental value in the municipalities surrounding the Doñana area. This decline in environmental value, as we will see next, worsened during the 1999–2016 period.

Figure 7c,d shows the incremental changes in surface area for various WEI classes during the two analyzed periods: 1999–2016 (Figure 7c) and 1991–2016 (Figure 7d). While a slight increase (2.72%) is observed in the highest WEI class ($90 < WEI_k < 100$) between 1999 and 2016, this is overshadowed by significant decreases in other high and mid-range classes. The area with environmental value between $70 < WEI_k < 80$ shows a substantial decline of 12.44%, and the $60 < WEI_k < 70$ class experienced a decrease of 5.58%. These substantial losses in high value areas necessarily imply a corresponding rise in areas with lower environmental value. This trend is confirmed by the increases observed in all lower WEI classes ($0 < WEI_k < 60$) during the period of 1999–2016. The most significant increase occurred in the $50 < WEI_k < 60$ class, with a growth of 6.76%.

Figure 7d reinforces this pattern for the entire 1991–2016 period. While the changes between 1991 and 1999 were less pronounced (as discussed earlier in Figure 7b), the overall trend is consistent. There was a qualitative shift towards a larger surface area with lower WEI values at the expense of areas with higher environmental value. This is evident in the decrease in surface area for the $60 < WEI_k < 70$ class (5.29%) and the $70 < WEI_k < 80$ class (7.06%) between 1991 and 2016. Similar to the 1999–2016 period, all lower WEI value classes ($0 < WEI_k < 60$) witnessed increases in surface area during the entire 1991–2016 timeframe.

4. Discussion

Table 8 shows the changes in land use during the period 1991–2016 in the Doñana area and the corresponding values of the WEI for each land use. The table has been ordered according to the predominant land uses in 2016 and displays the results corresponding to land uses covering 90% of the total study area. The complete results are included in the Supplementary Materials.

An interesting trend emerged when examining marshlands (MUCVA Codes 211 and 215) within the study area. While the total marshland area remained relatively constant between 1991 and 2016 (35,253.78 hectares in 1991 and a comparable area likely implied for 2016 based on the provided data), a significant shift in the typology of these marshlands is observed. In 1991, tidal marshes (MUCVA Code 211) constituted a minor portion of the total marshland area (around 0.49% or 1325.93 hectares). However, by 2016, tidal marshes had become the dominant marshland type, covering a substantially larger area (12.31% or 33,604.62 hectares). This is justified by a conversion of non-tidal marshlands (MUCVA Code 215) to tidal marshlands over the study period.

Table 8. Changes in land use during the period 1991–2016 in the Doñana area.

MUCVA Code	Land Use Description	WEI_k	Area (Has) 1991	% Area	WEI Contribution	Area (Has) 2016	% Over Total Area	WEI Contribution
211	Tidal marshes with vegetation	60	1325.94	0.49%	0.29	33,604.62	12.31%	7.38
931	Beaches, dunes, and sands	90	3959.00	1.46%	1.31	32,354.41	11.85%	10.66
421	Rice fields	50	30,930.18	11.37%	5.69	27,385.75	10.03%	5.01
411	Dryland herbaceous crops	53	22,386.62	8.23%	4.36	22,738.51	8.33%	4.41
520	Dense wooded formations: conifers	100	24,525.36	9.02%	9.02	22,412.36	8.21%	8.21
411	Irrigated herbaceous crops	53		0.00%	0.00	12,551.25	4.60%	2.44
423	Forced crops under plastic	30	62.29	0.02%	0.01	9378.08	3.43%	1.03
415	Dryland woody crops: olive groves	70	11,534.19	4.24%	2.97	8148.96	2.98%	2.09
921	Continuous pasture	80	7010.65	2.58%	2.06	8004.16	2.93%	2.35
415	Irrigated woody crops: olive trees	70		0.00%	0.00	5484.61	2.01%	1.41
935	Areas without vegetation due to cultivation	40	605.48	0.22%	0.09	5197.74	1.90%	0.76
825	Woody pasture: conifers. Scattered	100	147.62	0.05%	0.05	4732.43	1.73%	1.73
830	Woody pasture: eucalyptus	95	94.27	0.03%	0.03	4312.96	1.58%	1.50
621	Dense shrub with trees: dense conifers	100	7907.60	2.91%	2.91	4068.29	1.49%	1.49
141	Other technical infrastructures	10	0.00	0.00%	0.00	4059.47	1.49%	0.15
331	Continental lagoons	100	7685.80	2.83%	2.83	3976.26	1.46%	1.46
725	Scattered shrub with trees: conifers. Scattered	100	4161.92	1.53%	1.53	3469.38	1.27%	1.27
317	Natural rivers and channels: other riparian formations	100	3819.91	1.40%	1.40	3451.19	1.26%	1.26
131	Highways, motorways, and road links	20	7.05	0.00%	0.00	3442.35	1.26%	0.25
417	Dryland woody crops: vineyards	70	4018.58	1.48%	1.03	3215.76	1.18%	0.82
932	Rocks and bare soil	40		0.00%	0.00	3101.24	1.14%	0.45
530	Dense wooded formations: eucalyptus	90	11,445.96	4.21%	3.79	3058.12	1.12%	1.01
225	Industrial saltworks and crop parks	60	1638.13	0.60%	0.36	3055.46	1.12%	0.67
925	Pasture with clearings (rock, soil)	70	117.36	0.04%	0.03	2349.47	0.86%	0.60
821	Woody pasture: conifers. Dense	100	530.84	0.20%	0.20	2309.57	0.85%	0.85
431	Irrigated woody crops: citrus	70	1804.12	0.66%	0.46	2309.43	0.85%	0.59

It is important to note that the WEI value assigned to marshlands is independent of their specific type (tidal or non-tidal). Therefore, this change in marshland typology would not directly impact the overall WEI calculations for the entire study area.

It is important to consider a potential limitation when analyzing land use changes based on Table 8. The land use classification system employed in 1991 underwent modifications following the implementation of the SIOSE project's land use legend in the year 2005 [36]. This change in classification criteria could lead to situations where areas with unchanged land use between 1991 and 2016 might appear differently in the digital mapping due to the revised classification scheme. The example of beach and dune zones within the Doñana study area, which are discussed below, serves as a concrete illustration of this potential issue.

The second most prevalent land use type in 2016 is "beaches, dunes, and sands" (MUCVA Code 421), encompassing 11.85% of the total area (32,354.41 hectares). Interestingly, this same area was classified as "dense shrub with trees: scattered conifers" (MUCVA Code 625) in 1991.

However, a closer examination through satellite image visualization reveals that the land cover itself has not changed between 1991 and 2016. This discrepancy highlights the earlier mentioned limitation arising from the classification system modification following the SIOSE project [32]. In this specific case, the change in classification does not significantly impact the WEI analysis because the WEI value assigned to "beaches, dunes, and sands" (WEI_k = 90) is very similar to the average WEI value typically assigned to shrubland.

Table 8 highlights several key land use changes that have likely contributed to the observed decline in WEI across the study area. The most striking change is the substantial increase in greenhouse area. While greenhouses only occupied a negligible portion (0.02% or 62.29 hectares) in 1991, they expanded significantly to cover 3.43% of the total area (9378.08 hectares) by 2016. This expansion is confirmed through historical satellite image analysis (Figure 2) and was not due to classification changes. Since greenhouses have a low WEI value (30), their increased presence has undoubtedly contributed to the overall WEI decrease.

Another noteworthy change is the emergence of irrigated olive cultivation ("irrigated woody crops: olive trees", MUCVA Code 421) by 2016. This land use type was entirely absent in 1991, as olive cultivation relied solely on rainfall. In 2016, irrigated olive groves occupied 2.01% of the total area (5484.61 hectares), which aligns with observations from other studies conducted in Andalusia [37]. While positive from an economic perspective, irrigated olive cultivation has a lower WEI value (70) compared to traditional rainfed olive cultivation (likely closer to 75–80). This shift in cultivation practices could contribute to the decreasing WEI trend.

5. Conclusions

In this study, we utilized an adaptation of the Weighted Environmental Index (WEI), utilizing land use/land cover data from the MUCVA database, to analyze the environmental status evolution of municipalities surrounding the Doñana area between 1991 and 2016. The WEI index was originally designed for use with the SIOSE database, thus necessitating the redefinition of evaluation factor (F_i) values to appropriately align and complement the land use legend used in MUCVA.

WEI functions as an analytical instrument, offering a comprehensive overview of the environmental condition of the area. Examining its fluctuations over time has yielded insightful findings concerning the progression of environmental significance and the imperative for introducing protective measures. The adaptability of the WEI stems from the user's capacity to establish or adjust the values of the evaluation factors (F_i) to tailor them to the particular case study under examination.

By applying the aforementioned methodology to the municipalities surrounding the Doñana area, it has been determined that there are no significant changes in the distribution of the WEI index between 1991 and 1999. However, a general decrease in WEI values in the study area was observed during the period from 1999 to 2016. It was seen that in 1999, areas classified with high environmental value ($70 \leq WEI_k \leq 100$) accounted for 60.38% of the study area, while in 2016, this percentage had reduced to 51.19%. Furthermore, the surface area of areas classified with low environmental value had multiplied by four in the same period, increasing from 2.55% in 1999 to 8.41% in 2016.

The analysis of the temporal evolution of the WEI highlights the significance of the water stress and agronomic pressure affecting the area surrounding the Doñana Natural Park. The expansion of irrigated areas and greenhouse zones justifies this trend in the WEI evolution.

Future research should focus on understanding the broader environmental implications of the observed land use changes. This could involve investigating potential increases in water usage or pesticide application associated with the greenhouse expansion. Additionally, a more detailed spatial analysis of these changes across the study area might reveal specific zones experiencing the most significant environmental degradation. Finally, a comprehensive assessment that considers the economic benefits of irrigated olive cultivation alongside its potential environmental impact on WEI would provide valuable insights for sustainable land-use management practices within the Doñana area.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/su16104241/s1. Excel file with the details of the land use for the whole study area and detailed calculations.

Author Contributions: Conceptualization, J.-M.S.-G., J.R.-I. and C.P.R.; methodology, J.R.-I., C.P.R. and M.-E.R.-C.; formal analysis, J.-M.S.-G. and J.R.-I.; investigation J.-M.S.-G., J.R.-I. and C.P.R.; resources, J.-M.S.-G., C.P.R. and J.R.-I.; data curation, M.-E.R.-C. and J.R.-I.; writing—original draft preparation, J.-M.S.-G. and J.R.-I.; writing—review and editing, J.R.-I., C.P.R. and M.-E.R.-C.; supervision, J.-M.S.-G. and J.R.-I. All authors have read and agreed to the published version of the manuscript.

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