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Ecological Restoration Process of El Hito Saline Lagoon: Potential Biodiversity Gain in an Agro-Natural Environment

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Abstract: In the global context of biodiversity and ecosystem services loss, the integration of agriculture with ecological restoration is crucial. This study presents the biodiversity value (Bv) index for the first time as a tool for decision-making and securing funding for future restoration projects. The Bv index was used to assess biodiversity values in both restored natural habitats and agricultural areas in the saline lagoon of El Hito, a natural reserve located within an agricultural landscape in central Spain. Additionally, we estimated biodiversity gains from habitat transitions and explored the relationship between biodiversity, soil pH, and salinity. Sustainable agricultural practices, combined with ecological restoration methods, can lead to synergistic actions that reduce the potential detrimental effects of agriculture. Our results show that transitioning from agricultural to natural habitats consistently increases biodiversity. Among agricultural practices, multiannual vegetated fallows had the highest Bv values. Restoration led to a continuous biodiversity improvement, with the exception of the final transition from permanent pastures to *Elymus 1410*, which showed a slight decline in biodiversity. We also found that higher soil salinity and pH were associated with greater biodiversity values, likely due to historical agricultural practices that favored areas with lower salinity and pH for higher productivity. Salinity and pH act as limiting factors for biodiversity; therefore, agricultural plots with lower salinity and pH, particularly those adjacent to natural habitats, are expected to yield greater biodiversity gains if restored.

Keywords: agroecology; biodiversity index; ecological restoration; biodiversity-based agriculture; biodiversity gain; salty lagoon

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1. Introduction

There is a global concern about environmental degradation and the decrease in the provision of ecosystem services. This environmental degradation is occurring due to a wide array of anthropogenic impacts. Among these, land use changes, particularly the transformation of natural ecosystems into agricultural ecosystems, are one of the primary causes of species extinction and habitat degradation [1]. Intensive agriculture, with directly associated impacts from fertilizers and pesticides, is responsible for over 40% of the global decline in insect populations [2].

Intensive agriculture replaces numerous species with single edible species, which are typically non-native. This process reduces genetic diversity, habitat availability, and transforms landscapes to the detriment of ecosystem health. To increase crop outcomes, pesticides are commonly used to eliminate other species, and fertilizers are often used to enhance crop vegetative growth, which contributes to the pollution of soil and freshwater [3]. Intensive tillage further damages soil structure and microbiota, making it more vulnerable to erosion [4]. Intensive irrigation depletes soil aquifers, lowers the water table, and reduces water availability for other species [5].

Given these ecological realities, ecological restoration is emerging as a solution to environmental degradation, enabling the maintenance and recovery of ecosystem services, as well as supporting the regeneration of habitats for various species, helping to prevent their extinction. Ecological restoration is defined as "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" [6]. Alongside ecological restoration, organic and regenerative agriculture can facilitate the coexistence of human activities, economic development in rural areas, and biodiversity conservation [7].

Research into the effects on biodiversity has predominantly focused on natural or semi-natural ecosystems. However, in cultivated ecosystems, biodiversity is crucial for the provision of regulating and supporting ecosystem services, including pollination and nutrient distribution. In areas where these land uses coexist with natural ecosystems, ecosystem services are replenished due to the regeneration of soils, hydrological processes, and crop protection [8,9].

Agriculture and biodiversity conservation have traditionally been considered incompatible, as agriculture is one of the main drivers of species loss for many plant and animal taxa [10,11]. However, sustainable agricultural practices combined with ecological restoration methods can lead to synergistic actions, thereby reducing the potential detrimental effects of agriculture [12] and allowing the local community to thrive in a sustainable way. This is observed in the contact zones of both ecological and anthropogenic environments, as observed in El Hito Lagoon, a natural reserve located within an agricultural landscape in central Spain.

Historically, El Hito Lagoon has undergone a process of degradation, primarily due to the conversion of surrounding landscapes for agricultural purposes, which has led to the elimination of natural habitats [13]. This has triggered a series of cascading effects, including soil erosion from rainfall, resulting in sedimentation of the lagoon, thereby reducing its depth and altering the existing aquatic habitats. The decreased depth of the lagoon has attracted large colonies of flamingos in recent years, which have increased water turbidity, generating effects that have not previously been observed. Furthermore, over the past century, the lagoon basin has been used for landfill, illegal roads have been constructed that cut through the lagoon, and other structural elements were introduced, causing disruption of the landscape, including the creation of drainage systems to prevent the lagoon from filling (Figure 1). Additionally, pollution has increased due to the lack of efficient wastewater treatment facilities in the two surrounding urban centers and diffuse pollution from nearby agricultural activities [14].

To reverse these processes of environmental degradation, an EU LIFE project was initiated in 2021 to begin the purchase and restoration of the lagoon. This project focuses on removing illegal infrastructure within the lagoon, with the aim of improving wastewater treatments to prevent pollutant discharges into the lagoon, the ecological restoration of farmland within the reserve to recover priority habitats, and agri-environmental land stewardship programs to collaborate with farmers in the region.

The main sustainable agricultural measures promoted around the lagoon involve a series of stewardship agreements for the diversification of the agricultural system. Traditionally, cereals, sunflowers, legumes, and annual bare fallow lands have co-existed in the area. Within the framework of the LIFE project, a greater surface area of legumes has been promoted, and fodder crops and multi-year vegetated fallow lands have been introduced. There is a growing body of literature focused on the fact that an increase in crop diversity leads to a greater variety of habitat and, consequently, a more heterogeneous landscape [15,16].

Figure 1. Former livestock farm within the El Hito Lagoon Nature Reserve prior to the restoration of the lagoon.

Both cereals and sunflowers have been maintained under conventional agricultural practices in this region. Local practices in their cultivation have included the use of fertilizers, pesticides, and herbicides. Bare fallow lands typically undergo several tillages throughout the year. It is anticipated that cereal and sunflower areas will be replaced, in part, by legumes, fodder crops, and vegetated fallow lands in the coming years, while vegetated fallow lands will replace bare fallow lands entirely. The addition of these sustainable solutions to the landscape, with little to no chemical applications and tillage operations, results in an increase in the quality of the overall agroecosystem.

Furthermore, some critical agricultural areas with potential for transition to habitats listed in the EU Habitats Directive have been left uncultivated, and two restoration strategies have been implemented. Active restoration of *Lygeum spartum* grasslands (Priority Habitat 1510) has been carried out by planting more than 250,000 *Lygeum spartum* over an area of at least 4 hectares. Additionally, passive restoration has been undertaken, leaving several hectares in permanent fallow since the start of the project, allowing for natural colonization by the species characteristic of local habitats, as listed in the EU Habitats Directive, such as *Elymus sp* and *Puccinellia sp*.

In most restoration projects, obtaining data on biodiversity improvement and the recovery of ecosystems is often challenging and requires long-term data series, sometimes extending over more than 30 years [17], because agricultural ecosystems are transformed natural ecosystems over large temporal areas.

Securing continued funding for restoration projects can be particularly difficult without the substantiation of claims in biodiversity improvement or potential gains within shorter timeframes, which are necessary to encourage public funding. To quantify improvements in the ecosystem condition, a set of indicators were developed to facilitate the quantification of biodiversity improvements generated by restoration projects. To this end, the Global Nature Foundation has developed a methodology to measure "Biodiversity value" through the biodiversity value (Bv) index, which accounts for species richness, abundance, and the interest in each species within the context of the restoration project. These parameters were calculated by FGN for birds, flora, pollinators, aboveground arthropods, and soil arthropods. Additionally, salinity has been measured through electrical conductivity and pH tests at each sampling point to monitor the impact of salinity on these measures of biodiversity.

The UK government and other organizations such as the Wallacea Trust, Plan Vivo, and Verra have implemented alternative definitions of biodiversity value [18,19]. Unlike the

Bv method, these have generally been applied to calculate the environmental compensation obligations of various projects that involve habitat degradation. The Bv method allows for the quantification of biodiversity outcomes to be linked directly to specific practices (whether restorative or not) and for these impacts to be forecasted.

In this study, we aim to (1) calculate the biodiversity value associated with each type of habitat in El Hito Lagoon, with the goal of identifying the most valuable habitats for biodiversity. The hypothesis is that conventional agricultural habitats (cereal crops, sunflowers, bare fallow lands) will have the lowest associated biodiversity value (Bv) and the habitats listed in the EU Habitats Directive (Elymus 1410 and 1510) will have the highest. (2) Additionally, we aim to calculate the potential for biodiversity gain from substituting conventional agricultural land uses by higher-quality habitats. (3) Finally, this study aims to examine the relationship between salinity, pH, and biodiversity within the study area in order to assess and control the impact of salinity and pH on the calculated biodiversity value and in the restoration potential of some areas.

2. Materials and Methods

2.1. Habitats of the Study Area

In Table 1, the different types of habitats assessed, a description of them, and their coding are shown.

Table 1. Abbreviations associated with each habitat measured.

Type of Habitat	Code	Description
Non-improved agricultural habitat	FL	Fallow land with bare soil
Non-improved agricultural habitat	C	Cereal crops
Non-improved agricultural habitat	G	Sunflower crops
Improved agricultural habitat	FCs	Fodder crops
Improved agricultural habitat	LCs	Legume crops
Improved agricultural habitat	VFL_1	Vegetated fallow land 1 year
Improved agricultural habitat	VFL_2	Vegetated fallow land 2 years
Restoration habitats	PP	Permanent pastures
Restoration habitats	NV	Nitrophilous vegetation
Restoration habitats	EU_T	Transition to EU habitat
Restoration habitats	1510_R	Restoration of 1510
Habitats of the EU Habitats Directive	1510	Priority Habitat 1510 "albardinal"
Habitats of the EU Habitats Directive	1410	Habitat 1410 with Elymus

In Figure 2, the selected points for the initial sampling can be observed. The plots and their habitat types were defined through a botanical study [20], later modified with data from the Global Nature Foundation. Three sampling points per habitat were determined using random sampling with the ArcGIS program, and one point was strategically chosen for bird listening stations.

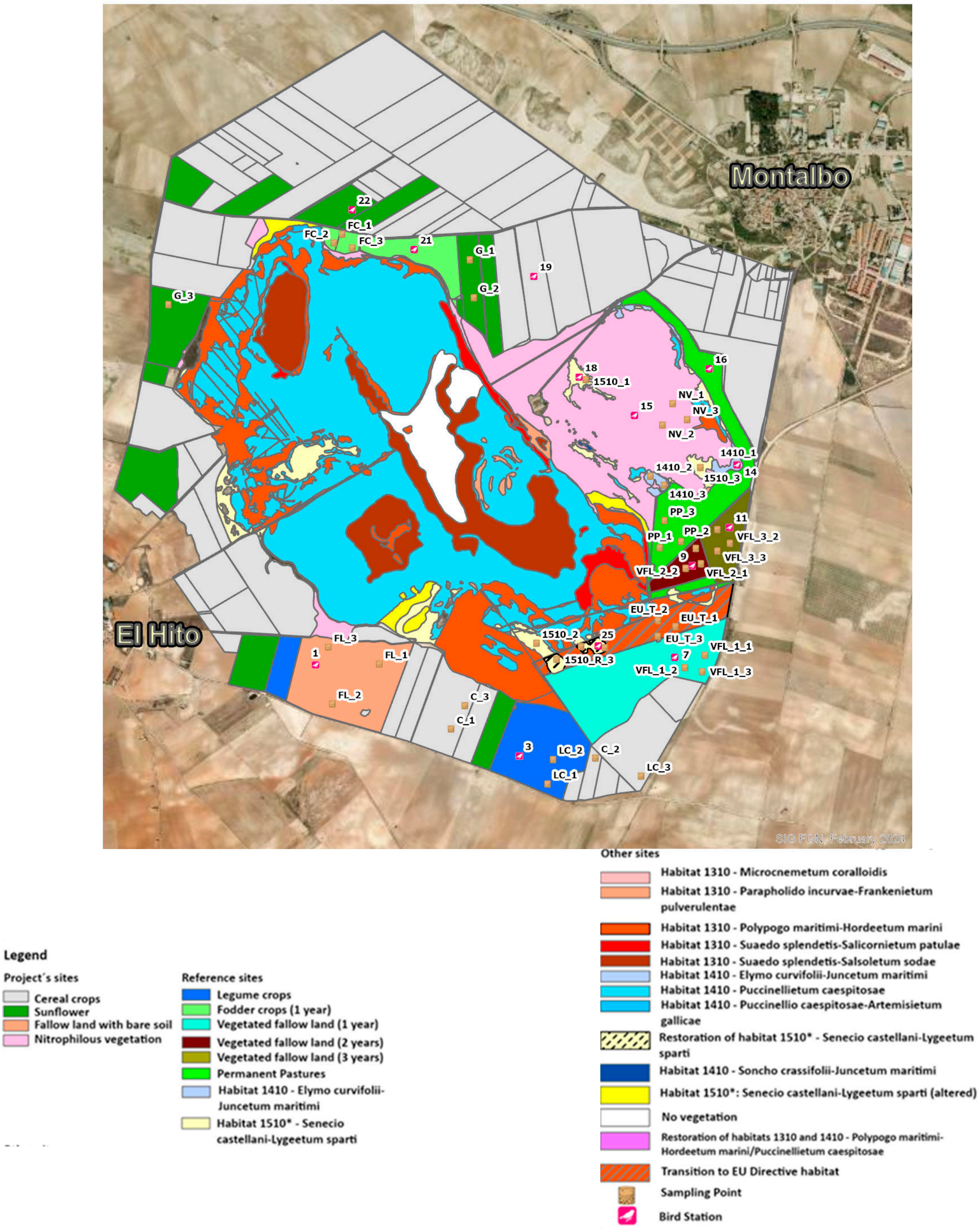

Figure 2. Habitats distribution and sampling points.

2.2. Proposal of a Biodiversity Index

To define biodiversity outcomes, the concept of the basket of metrics was used, understanding biodiversity as the biodiversity value (Bv) obtained through the measurement of 5 different metrics, which are measured in the working area. Metrics are selected and included according to 4 principles: (1) biodiversity groups that influence and are influenced by the ecosystem services of the habitat under study, linked to key functions in the ecosystem, (2) biodiversity groups influence and are influenced by the anthropogenic activities taking place in the ecosystem (agriculture and livestock farming), (3) represent different levels of complexity (simple and complex organisms), and (4) act at different levels, below and above ground, representing a spectrum of trophic levels.

Measurement methodologies are shown in Figure 3, and consisted of the environmental DNA of soil arthropods analysis, 2 × 10 m transects of flora analysis, 2 min aspirations of aboveground arthropods using a BLACK+DECKER BCBLV36B-XJ (Towson, MD, USA) with entomological net incorporated, 48 h placement of Blue Vane traps for pollinators, and listening stations for birds following the SACRE Program (SEO Birdlife).

Figure 3. Sampling methods for (**A**) pollinators with Blue Vane trap. (**B**) Aboveground arthropods with BLACK+DECKER BCBLV36B-XJ garden vacuum. (**C**) Two-square-meter quadrats used to measure flora. (**D**) Soil bacteria, fungi, and arthropods sampling by a soil auger.

After the field measurements, the parameter total Bv was calculated as follows:

$$\text{TotalBv habitat } (i) = \frac{BvSoilA + BvFlora + Bv\ AbovegroundA + BvPollinators + Bvbirds}{5}$$

1. *BvSoilA*: biodiversity value of soil arthropods;
2. *BvFlora*: biodiversity value of flora;
3. *BvAbovegroundA*: biodiversity value of aboveground arthropods;
4. *BvPollinators*: biodiversity value of pollinators;
5. *BvBirds:* biodiversity value of birds.

Bv is understood as a normalized value between 1 and 5 and is calculated as follows in metrics flora, aboveground arthropods, pollinators, and birds.

$$Bv = (R \times A \times I)^{\frac{1}{3}}$$

6. *R*: Richness;
7. *A:* Abundance;
8. *I*: Interest.

Since three different sampling points are selected per habitat, the Bv value will be the average of the three individual biodiversity values obtained per habitat.

$$Bv_{h(i),\, m(z)} = \left(Bv_{p1,\, h(i),\, v(z)} + Bv_{p2,\, h(i),\, v(z)} + Bv_{p3,\, h(i),\, v(z)}\right)\backslash 3$$

p(x): sampling point x from habitat i and metric (z).

The variables of abundance and richness are highly sensitive to the season of the year in which monitoring takes place, as well as to the climatic conditions of the year, especially in the Mediterranean where annual precipitation can be highly variable [21]. Therefore, a two-linear regression is performed taking into consideration the values of abundance and richness obtained in all monitoring points so that specific thresholds can be created for normalization between 1 and 5 of the abundance and richness in the formula.

In scenarios of limited abundance such as metric flora, in which the percentage of soil coverage per species is measured and ranks between 0 and 100%, the continuous values between 1 and 5 for abundance are calculated as follows, avoiding the two-linear regression:

$$Abundance = 1 + 4 \cdot \left(\sum_{i\, \in Q > 0} Area(i) \right)$$

Abundance = 1 + 4 × (sum of all *Area (i)* from taxa with quality > 0).

In scenarios of unlimited abundance such as metrics aboveground arthropods, pollinators, and birds, the continuous values between 1 and 5 for abundance are calculated as follows using the proposed two-linear regression:

$$LogTotalCount = \log(Count(1) + \ldots + Count(N)).$$

Reference points for two phase linear regression are defined as follows:

Min(LogTotalCount) --> 1, Median(LogTotalCount) --> 3 y Max(LogTotalCount) --> 5

Continuous values for richness between 1 and 5 are always calculated through the two-linear regression, with reference points as follows:

Min(NbSpecies) --> 1, Median(NbSpecies) --> 3 y Max(NbSpecies) --> 5

where *NbSpecies* represents the number of species with at least one individual present during the sampling

The parameter *interest* (discrete number between 0 and 5) will be assigned to each species according to two compatible criteria: (1) conservation status of the species or habitats assessed and (2) amount of information an organism offers about the overall habitat. The categories considered for the different metrics are defined in Tables 2–4.

Table 2. Thresholds of interest for flora.

Flora—Thresholds of Interest (I):
0 --> Alien invasive species/Bare soil/Mulch.
1 --> Annual herbaceous Poaceae species or other grass plants without pollen.
2 --> Annual herbaceous plants with pollen and biannual (or longer) herbaceous Poacea species.
3 --> Biannual (or more) herbaceous plants with pollen.
4 --> Woody shrubs (<3 m) or plants included in habitats of the EU Habitats Directive.
5 --> Trees (>3 m) or plants included in priority habitats of the EU Habitats Directive.

Table 3. Thresholds of interest for aboveground arthropods and pollinators.

Arthropods—Thresholds of Interest (I):
0 --> Alien invasive species.
1 --> Important pests.
2 --> Non-pollinating phytophagous species, generalist.
3 --> Detritivores, coprophagous, xylophagous, fungivores, saprophagous, polyphagous, and natural enemies and predators competitive in low-quality and degraded habitats (Araneae, Formicidae).
4 --> Natural enemies, pollinating phytophagous, and pollinators less competitive in low-quality and degraded habitats.
5 --> Endangered species.

Table 4. Thresholds of interest for birds.

Birds—Thresholds of Interest (I):
0 --> Alien invasive species
1 --> LC/L (least concern/listed)
2 --> NT (near threatened)
3 --> VU (vulnerable)
4 --> EN (endangered)
5 --> CR (critical risk)

In order to assign the value of interest to the whole sample, first the *weight (i)* is calculated based on the previously defined parameter *count(i)*

$$Weight(i) = \log(\max(Count(i), 2))$$

Subsequently, the parameter *RelativeWeight(i)* is calculated, which normalizes the weights so that their sum equals 1.

$$RelativeWeight(i) = \frac{Weight(i)}{(Weight(1) + \ldots + Weight(N))}$$

where N is the total number of taxa.

Finally, *interest (I)* is calculated as follows:

$$Interest = \frac{\sum_{\substack{i \\ RelativeWeight(i) \, * \, Quality(i) > 0}} RelativeWeight(i) \, * \, Quality(i)}{\sum_{\substack{i \\ RelativeWeight(i) \, * \, Quality(i) > 0}} RelativeWeight(i)}$$

Considering only species where *RelativeWeight(i)* $*$ *Quality(i) > 0*.

In this way, *Quality(i)* is weighted by *RelativeWeight(i)*, and species with a non-positive *quality* are excluded (for instance, alien invasive species).

In the case of the metric soil arthropods and given the difficulty of accessing the parameter abundance through current monitoring methodologies (environmental DNA offers only information about richness), a different approach was used for calculating Bv. The Soil Biodiversity Quality Index or QBS-ar [22], based on calculating the Eco-Morphological Index (EMI), assigns a value between 5 and 20 to soil microarthropod communities based on their morphological adaptation to the soil habitat [23]. The QBS score can range between 1 and 375, and those values were assigned in a continuous scale between 1 and 5 to form the Bv index, using a two-phase linear regression, with reference points defined in Table 5.

Table 5. Bv values for the metric soil arthropods.

Soil Arthropods—Thresholds of Interest (I):
1--> score of 5 in QBS-ar 3--> score of 190 in QBS-ar 5--> score of 375 in QBS-ar

Considering the different Bv values calculated for each type of habitat, potential biodiversity gains were calculated as follows:

$$Biodiversity\ gain\ habitat\ a\ \rightarrow\ habitat\ b = \left(\left(\frac{TotalBv_{habitat\ b}}{TotalBv_{habitat\ a}}\right) - 1\right) * 100$$

2.3. Measurement of Soil pH and Salinity

A pH meter (CRISON pH 25 model, Barcelona, Spain) was used to determine the pH reading in a soil/water paste at a 1:5 ratio [24]. Soil salinity was measured using electrical conductivity following standardized methodologies [25,26]. A conductivity meter (CRISON CM 35+ model, Barcelona, Spain) was used to determine the electrical conductivity in a soil/water paste at a 1:5 ratio. The measurement was taken in July under sunny weather conditions; however, it is possible that some surface salinity was lost due to rainfall earlier in the week, which could affect the results. A sample was taken at each of the sampling points across all habitats (3 sampling points per habitat) with a total of 39 sampling points. A Generalized Mixed Linear Model (GLMM) was generated to study the response of the response variable Total_Bv to pH and salinity. Total_Bv was calculated for each sampling point, so the sampling points were not independent of each other, as three sampling points were taken in each habitat. Therefore, the habitat variable was introduced as a random effect within the model.

Additionally, a linear model was conducted to study the relationship between salinity, measured as electrical conductivity (dS/m), and pH. ANOVA tests were used to calculate the significance of all the model variables using R 4.1.0.

3. Results

3.1. Biodiversity Values Bv

In Figure 4, the Bv values for each habitat are represented. It can be interpreted that the peaks on the left side of the figure represent higher Bv values, while the peaks on the right indicate lower Bv values.

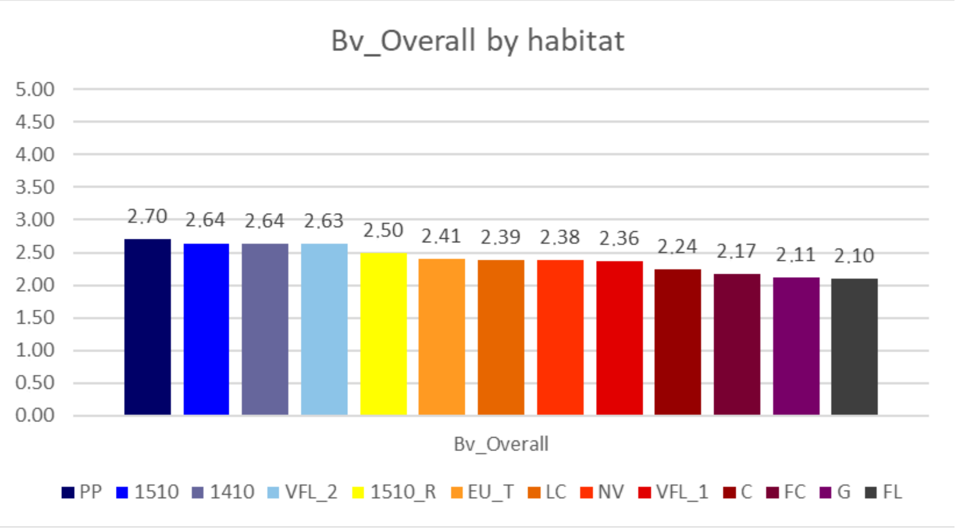

Figure 4. Histogram representing the total Bv values of each measured habitat.

As hypothesized, the European Directive Habitats (Elymus 1410 and 1510) received some of the highest scores, only surpassed by the restoration habitat PP. They are closely followed by improved agricultural habitat VFL_2 (which can be considered a PP in earlier stages) and restoration habitats 1510_R and EU_T. Improved agricultural habitat LC and restoration habitat NV score similarly, while non-improved agricultural habitats C, G, and FL received the lowest scores, as predicted. Improved agricultural habitat VFL_1 scores higher than agricultural habitats without ecological interventions (being an earlier stage of VFL_2).

In the case of PP, it unexpectedly achieved a slightly higher score than European Directive Habitats Elymus 1410 and 1510. Also, contrary to expectations, fodder crops, which were implemented as a measure to reconcile conservation with agricultural production, received lower Bv values than cereal crops.

Bare fallow land (habitat FL) obtained the lowest biodiversity scores, showing a negative balance in comparison to the other agricultural use types.

In Table 6, the score of each Bv_metric for each habitat can be observed as well as total Bv.

Table 6. Bv values calculated for all metrics in all habitats. Total Bv for each habitat is shown on the final right column.

Biodiversity Metrics Bv Value All Metrics						
Land Use	**Bv_SoilA**	**Bv_Flora**	**Bv_Arthropods**	**Bv_Pollinators**	**Bv_Birds**	**Bv_Overall**
PP	1.05	3.58	3.34	2.70	2.85	2.70
1510	1.05	4.51	2.68	2.73	2.23	2.64
1410	1.00	4.24	2.60	2.62	2.72	2.64
VFL_2	1.65	3.13	2.48	3.26	2.64	2.63
1510_R	1.00	3.69	2.62	2.74	2.43	2.50
EU_T	1.05	2.85	2.72	3.05	2.37	2.41
LC	1.22	2.45	2.40	3.08	2.79	2.39
NV	1.00	2.58	2.68	2.80	2.82	2.38
VFL_1	1.05	2.81	2.63	2.67	2.64	2.36
C	1.11	1.87	2.70	3.29	2.22	2.24
FC	1.00	2.17	2.77	2.63	2.29	2.17
G	1.49	1.88	1.76	2.71	2.73	2.11
FL	1.05	1.21	2.51	2.95	2.79	2.10

The metric BvFlora scored very highly for habitats that are considered natural and ecologically desirable, whereas their values were much lower for agricultural and transformed habitats. BvSoilA generally scored very low across all habitats, although its score was higher in sunflower (G), legume crops (LCs), and 2-year vegetated fallow land (VFL_2).

No clear patterns are observed in the BvArthropods values. The highest value was found in permanent pastures (PPs), while the lowest was in sunflower (G). The values for the other habitats were similar.

BvPollinators scored higher in agricultural habitats such as cereal (C), legume crops (LCs), and 2-year vegetated fallow land (VFL_2). Conversely, contrary to expectations, values were lower in EU Directive Habitats and habitats undergoing restoration.

Birds have broader roaming ranges, and BvBirds showed very similar scores across all habitats. Interestingly, the lowest value was observed in cereal (C), followed by EU Habitat 1510. The highest value was recorded in habitat permanent pastures (PPs).

On the other hand, Table 7 presents the correlation values between the Bv indices of each metric. The most substantial correlations are observed between soil arthropods and pollinators, with a correlation coefficient of 0.46, followed by soil flora and aboveground arthropods, which exhibit a correlation of 0.37. The strong negative correlation between aboveground arthropods and soil arthropods, with a value of −0.59, is also noteworthy. Birds were not well correlated with any other metric.

Table 7. Correlation values between Bv indices of each metric.

Correlation Values Between Bv Indices of Each Metric					
	Bv_SoilA	**Bv_Flora**	**Bv_Arthropods**	**Bv_Pollinators**	**Bv_Birds**
Bv_SoilA	-	−0.18	−0.59	0.46	0.21
Bv_Flora	−0.18	-	0.37	−0.36	−0.14
Bv_Arthropods	−0.59	0.37	-	−0.09	−0.12
Bv_Pollinators	0.46	−0.36	−0.09	-	−0.15
Bv_Birds	0.21	−0.14	−0.12	−0.15	-

3.2. Potential Biodiversity Gains (or Losses)

This study was performed under the hypothesis that conventional agricultural habitats (cereal crops, sunflowers, bare fallow lands), which are considered degraded, will have the lowest associated biodiversity value (Bv), with a potential biodiversity gain if replaced by higher-quality habitats. To test this hypothesis, the estimated percentages of biodiversity gain (or loss) for transitions from conventional agricultural habitats (FL, G, C) to other types of habitats can be seen in Tables 8–10.

Table 8. Potential biodiversity gain/loss replacing bare fallow land.

Potential Biodiversity Gain/Loss Replacing Bare Fallow Land	
Type of Substitution	**Biodiversity Gain (%)**
Bare fallow land (FL) --> legume crops (LCs)	13.61%
Bare fallow land (FL) --> fodder crops (FCs)	3.33%
Bare fallow land (FL) --> cereal (C)	6.47%
Bare fallow land (FL) --> sunflower (G)	0.57%
Bare fallow land (FL) --> vegetated fallow land 1 year (VFL_1)	12.27%
Bare fallow land (FL) --> vegetated fallow land 2 years (VFL_2)	25.21%
Bare fallow land (FL) --> permanent pastures (PPs)	28.64%
Bare fallow land (FL) --> transition to EU Directive Habitat (EU_T)	14.56%
Bare fallow land (FL) --> restoration of 1510 (1510_R)	18.74%
Bare fallow land (FL) --> NV	13.04%
Bare fallow land (FL) --> Elymus 1410 (1410)	25.40%
Bare fallow land (FL) --> 1510 (1510)	25.59%
Average gain	15.62%

Table 9. Potential biodiversity gain/loss replacing sunflower.

Potential Biodiversity Gain/Loss Replacing Sunflower	
Type of Substitution	**Biodiversity Gain (%)**
Sunflower (G) --> legume crop (LC)	12.96%
Sunflower (G) --> bare fallow land (FL)	0.57%
Sunflower (G) --> cereal (C)	−5.54%
Sunflower (G) --> fodder crop (FC)	2.74%
Sunflower (G) --> vegetated fallow land 1 year (VFL_1)	11.64%
Sunflower (G) --> vegetated fallow land 2 years (VFL_2)	24.50%
Sunflower (G) --> permanent pastures (PPs)	27.91%
Sunflower (G) --> transition to EU Directive Habitat (EU_T)	13.91%
Sunflower (G) --> restoration of 1510 (1510_R)	18.07%
Sunflower (G) --> NV	12.39%
Sunflower (G) --> Elymus 1410 (1410)	24.69%
Sunflower (G) --> 1510	24.88%
Average gain	14.06%

Table 10. Potential biodiversity gain/loss replacing cereals.

Potential Biodiversity Gain/Loss Replacing Cereal	
Type of Substitution	**Biodiversity Gain (%)**
Cereal (C) --> legume crop (LC)	6.70%
Cereal (C) --> sunflower (G)	−5.54%
Cereal (C) --> fallow land (FL)	−6.08%
Cereal (C) --> fodder crop (FC)	−2.95%
Cereal (C) --> vegetated fallow land 1 year (VFL_1)	5.45%
Cereal (C) --> vegetated fallow land 2 years (VFL_2)	17.61%
Cereal (C) --> permanent pastures (PPs)	20.82%
Cereal (C) --> transition to EU Directive Habitat (EU_T)	7.60%
Cereal (C) --> restoration of 1510 (1510_R)	11.53%
Cereal (C) --> NV	6.17%
Cereal (C) --> Elymus 1410 (1410)	17.78%
Cereal (C) --> 1510 (1510)	17.96%
Average gain	8.09%

It appears that the transition of agricultural habitats to other types of habitat generates potential biodiversity gains, except for the improved agricultural habitat FC. This supports our hypothesis with this exception.

The other hypothesis was that the habitats listed in the EU Habitats Directive (Elymus 1410 and 1510) would have the highest scores, with a potential biodiversity gain when replaced with another type of habitat. In order to test this hypothesis, the estimated percentages of biodiversity gain (or loss) for transitioning from any habitat type to Elymus 1410 and 1510 can be seen in Tables 11 and 12. Negative values are highlighted in red, while the highest gains are highlighted in bold.

Table 11. Potential biodiversity gain/loss implementing Elymus 1410.

Potential Biodiversity Gain/Loss Implementing Elymus 1410	
Type of Substitution	**Biodiversity Gain (%)**
Bare fallow land (FL) --> Elymus 1410	25.40%
Sunflower (G) --> Elymus 1410	24.69%
Fodder crops (FCs) --> Elymus 1410	21.36%
Cereal (C) --> Elymus 1410	17.78%
Legume crops (LCs) --> Elymus 1410	10.39%
Vegetated fallow land 1 year (VFL_1) --> Elymus 1410	11.69%
Vegetated fallow land 2 years (VFL_2) --> Elymus 1410	0.15%
Permanent pastures (PPs) --> Elymus 1410	−2.51%
Transition to EU Directive Habitat (EU_T) --> Elymus 1410	9.47%
NV --> Elymus 1410	10.94%
Restoration of 1510 (1510_R) --> Elymus 1410	5.61%
1510 --> Elymus 1410	−0.15%
Average gain	11.24%

It is observed that potential gains in biodiversity, measured as Bv, are when transitioning from any type of habitat to habitats listed in the EU Habitats Directive (Elymus 1410 and 1510), except for the restoration habitat permanent pastures (PPs). This proves the second part of our hypothesis with this exception.

Regarding other potential biodiversity gains, it must be taken into consideration that not all transitions are possible, and potential gains (or losses) will only be calculated for those that are potentially implementable in the El Hito Lagoon. Table 13 shows the potential biodiversity gain (or loss) for these types of transitions, taking as a reference cereal crops (which has the best Bv among conventional agricultural habitats).

Table 12. Potential biodiversity gain/loss implementing habitat 1510.

Potential Biodiversity Gain/Loss Implementing 1510	
Type of Substitution	**Biodiversity Gain (%)**
Bare fallow land (FL) --> 1510	25.59%
Sunflower (G) --> 1510	24.88%
Fodder crops (FCs) --> 1510	21.55%
Cereal (C) --> 1510	17.96%
Legume crops (LCs) --> 1510	10.55%
Vegetated fallow land 1 year (VFL_1) --> 1510	11.86%
Vegetated fallow land 2 years (VFL_2) --> 1510	0.30%
Permanent pastures (PPs) --> 1510	−2.37%
Transition to EU Directive Habitat (EU_T) --> 1510	9.63%
NV --> 1510	11.11%
Restoration of 1510 (1510_R) --> 1510	5.77%
Elymus 1410 --> 1510	0.15%
Average gain	11.42%

Table 13. Potential biodiversity gain/loss of other transitions.

Potential Biodiversity Gain/Loss of Other Transitions	
Type of Substitution	**Biodiversity Gain (%)**
Cereal (C) --> vegetated fallow land 1 year (VFL_1)	5.45%
Vegetated fallow land 1 year (VFL_1) --> vegetated fallow land 2 years (VFL_2)	11.53%
Vegetated fallow land 2 year (VFL_2) --> permanent pastures (PPs)	2.74%
Permanent pastures (PPs) --> Elymus 1410 (1410)	−2.51%
Cereal (C) --> European Union Transition (EU_T)	11.53%
European Union Transition (EU_T) --> restoration of 1510 (1510_R)	3.65%
Restoration of 1510 (1510_R) --> 1510	5.77%
Average gain	5.45%

When an agricultural plot is left uncultivated in El Hito Lagoon, two types of transitions start to occur: (1) an early stage of the restoration habitat permanent pastures (PPs) starts to develop through VFL_1 and VFL_2; (2) specific flora more resistant to higher pH and higher salinity start to thrive through EU_T and 1510_R. According to the results seen in El Hito Lagoon, PPs will start to transition to Elymus 1410 in mature stages of restoration (although this will depend on orographic and soil conditions), while 1510_R will transition to 1510, being an active restauration of this concrete type of habitat. EU_T could transition to 1510, Puccinellia 1410, or 1310 depending again on the soil characteristics and orographic conditions.

Following the course of the first type of transition and taking as a reference cereal crops for the starting point, the potential biodiversity gain expected is 5.45% when transitioning from C to VFL_1, 11.53% from VFL_1 to VFL_2, 2.74% from VFL_2 to PP, and −2.51% from PP to Elymus 1410, for a compounded potential gain of 17.78% at the end of the transition.

Following the course of the second type of transition and taking as a reference cereal crops for the starting point, the potential biodiversity gain expected is 11.53% when transitioning from C to EU_T, 3.65% from EU_T to 1510_R, and 5.77% from 1510_R to 1510, for a compounded potential gain of 17.96% at the end of the transition.

3.3. Relation of Bv with Soil Salinity and pH

The data obtained for pH and salinity at each sampling point can be found in Table 14. The salinity, measured as electrical conductivity (dS/m), ranged from 0.42 (non-saline) to 9.1 (extremely saline). Meanwhile, the pH ranged from 7.2 (neutral) to 8.1 (alkaline). More saline soils generally had a higher pH than the average. These were the soils from habitats

1510_R and NV. In contrast, soils associated with agricultural habitats such as cereal or legume crops showed little to no salinity and more neutral pH levels.

Table 14. pH and conductivity per sampling point.

pH and Conductivity per Sampling Point			
Habitat	**Sampling Point**	**Conductivity**	**pH**
1410	1410_1	5	7.9
1410	1410_2	3.9	7.8
1410	1410_3	2.7	7.7
1510	1510_1	2.2	7.8
1510	1510_2	2.6	7.7
1510	1510_3	2.5	7.5
1510_R	1510_R_1	9.1	8.1
1510_R	1510_R_2	6.6	8.1
1510_R	1510_R_3	8.05	8
C	C_1	2.2	7.3
C	C_2	1.8	7.5
C	C_3	0.93	7.5
EU_T	EU_T_1	8	7.7
EU_T	EU_T_2	1.8	8.1
EU_T	EU_T_3	2	7.6
FC	FC_1	2.2	7.6
FC	FC_2	1.9	7.5
FC	FC_3	3.1	7.3
FL	FL_1	2.1	7.6
FL	FL_2	1.8	7.3
FL	FL_3	1.8	7.3
G	G_1	1.82	7.2
G	G_2	2.05	7.4
G	G_3	1.1	7.3
LC	LC_1	0.67	7.5
LC	LC_2	1.7	7.3
LC	LC_3	0.42	7.7
NV	NV_1	3.4	7.6
NV	NV_2	7	7.9
NV	NV_3	8.1	7.8
PP	PP_1	2.3	7.8
PP	PP_2	2.2	7.8
PP	PP_3	3.8	7.5
VFL_1	VFL_1_1	4.2	7.65
VFL_1	VFL_1_2	4.6	7.7
VFL_1	VFL_1_3	2.005	7.8
VFL_2	VFL_2_1	2.3	7.8
VFL_2	VFL_2_2	2.3	7.7
VFL_2	VFL_2_3	2	7.7

The relationship between pH and salinity is significant, with a Pr (>F) less than 0.05, as can be seen in Table 15.

Table 15. ANOVA test results of Lm between electric conductivity and pH.

Lm Electric Conductivity/pH				
Response: Electric Conductivity	**Sum sq**	**Df**	**F Value**	**Pr (>F)**
pH	617.030	1	17.764	0.0001542 ***
Residuals	128.519,37			

Signif. codes: 0 '***'.

A linear regression was performed to observe the significant relationship between salinity (electrical conductivity in dS/m) and pH. As can be seen in the following Figure 5, this relationship is positive. Therefore, lower pH levels are associated with higher salinity. These results are consistent with previous analyzes of salinity and pH conducted in El Hito, where a positive relationship between pH and salinity was also found [13].

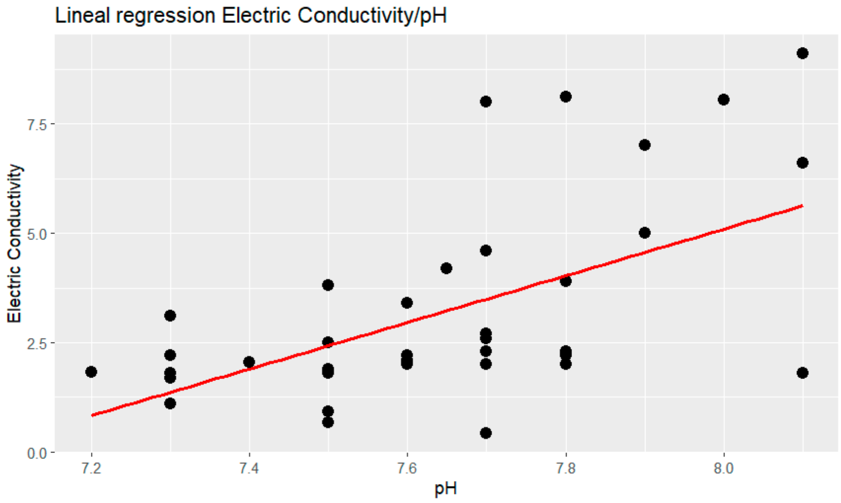

Figure 5. Linear regression between electric conductivity and pH.

Regarding the relationship between total Bv, which represents the biodiversity value considering all metrics, and pH and salinity, the only significant variable was pH, as shown in Table 16.

Table 16. ANOVA results of GLMM between total Bv and electrical conductivity and pH.

	Model_Total_Bv		
Response: Total_Bv	**Chisq**	**Df**	**Pr (>Chisq)**
Electric Conductivity	0.07	1	0.791357
pH	10.31	1	0.001323 *

Signif. codes: '*' 0.05 ' ' 1.

After performing a linear regression as shown in Figure 6, between total Bv and pH, it is observed that, in general, a higher pH is associated with a higher total Bv.

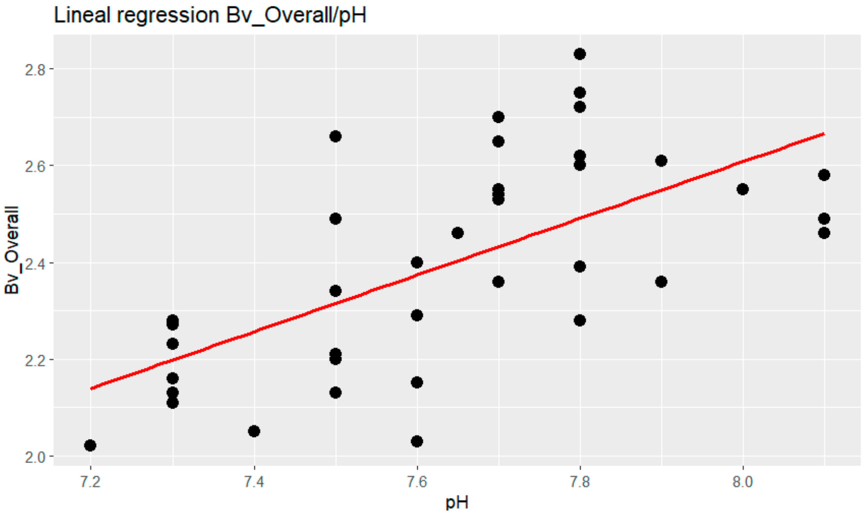

Figure 6. Linear regression between total Bv and pH.

4. Discussion

This is the first study to utilize the Bv index to estimate the biodiversity value of each habitat within an agro-environmental and ecological restoration context. Our findings provide valuable insights into the importance of each habitat type for biodiversity and allow us to estimate the potential biodiversity gain (or loss) under different crop and fallow scenarios. Additionally, the results offer an estimation of the biodiversity gain (or loss) that could be achieved if agricultural land were to be restored to the natural habitats of the study area.

Firstly, it is noteworthy that our initial hypothesis regarding the lower biodiversity value for conventional agricultural habitats (C, G, FL) has been confirmed, except for improved agricultural habitat fodder crops (FCs), which does not deliver a better biodiversity outcome than cereals (Cs). This result was surprising since fodder crops were introduced as an agro-environmental improvement measure based on the findings of various authors [27–29]. This could be due to the poor establishment of the fodder crop at the time of sampling. We observed that the preferred species (*Lolium rigidum* and *Bassia scoparia*) had very low ground cover. The climatic conditions of this year affecting the condition of the crop, along with the timing of the sampling, could be masking the beneficial effect that the introduction of fodder crops has in an intercropping scheme [30,31]. It is expected that subsequent samplings, planned for September 2024, when the fodder crops are fully established, as well as the consecutive years samplings, will allow for adequate measurement of the effect of these crops on biodiversity.

It must also be noted that the improved agricultural habitats LC, VFL_1, and VFL_2 show a better performance than all conventional agricultural habitats. Legume crops were also introduced as an agro-environmental improvement measure based on the findings of various authors [28,32–36], showing that a potential biodiversity gain can be expected if these measures are implemented at larger spatial scales. Further, 1-year vegetated fallow lands (VFL_1) also showed better results than conventional agricultural habitats, and when the vegetated fallow land is in place for 2 years or more (VFL_2), the biodiversity values grow exponentially.

The second part of the hypothesis was that the habitats listed in the EU Habitats Directive would deliver the highest scores, also confirmed with the exception of restoration habitat permanent pastures (PPs). The PP in El Hito Lagoon is an earlier stage of Elymus 1410 (depending on orographic and soil conditions), and the biodiversity values in this case were different to what was expected because restored habitats usually show less biodiversity than reference ecosystems, according to the findings of different authors [37,38].

As mentioned before, when an agricultural plot is left uncultivated in El Hito Lagoon, two types of transitions start to occur in a linear fashion. In type of transition (1), the agricultural plot transitions to VFL_1, which in turn transitions to VFL_2, PP, and ultimately to Elymus 1410 under certain soil and orographic conditions. In type of transition (2), the agricultural plot transitions to EU_T or 1510_R, and ultimately 1510, Puccinellia 1410, or 1310 (again, depending on certain soil, surrounding habitats, and orographic conditions).

The Global Nature Foundation found that under the same state of passive restoration, some habitats transition to VFL_1 and VFL_2, while others transition to EU_T. The transition to 1510_R was promoted by active restoration (planting of *Lygeum spartum*) on plots that had passively transitioned to EU_T. In EU_T, the establishment of species such as *Puccinellia* spp. and *Hordeum marinum* could lead to the formation of habitats listed in the EU Directive, such as Puccinellia 1410 and/or 1310. Based on findings of salinity (measured through electrical conductivity) and pH measurements in each of the transition habitats, soils with higher salinity and pH will tend to deliver EU_T and 1510_R types of transitions, while lower values will tend to promote the establishment of VFL_1, VFL_2, and PPs.

In each type of transition, there is a continuous improvement in biodiversity value from the early stages to the latter stages of the restoration process, except for the ultimate transition of PP into Elymus 1410, which might deliver slightly lower values according to this study. Comparisons between habitats of different transitions (VFL_1/VFL_2/PP against EU_T/1510_R) have not been made since soil parameters and orographic conditions are the factors determining the chain of events taking place, and the occurrence of one transition or the other cannot be forced by the project developer.

Further study of habitats VFL_1, VFL_2, PP, EU_T, and 1510_R in the coming years will provide a clearer understanding of the establishment processes of habitats of the EU Habitats Directive, or whether other habitats may emerge. As other authors have suggested [39], it is crucial to document both active and passive ecological restoration processes over extended periods that approximate ecological time scales. This will enable a more comprehensive understanding of the most effective restoration methods and help minimize the risk of implementing inefficient restoration methodologies.

Continuing with one of the central points of this study, this estimated biodiversity gain could help attract the interest of potential public and private funders, helping to unlock capital to support the restoration of the lagoon and promote its biodiversity. The biodiversity gains methodology allows us to infer increases in biodiversity that would occur following specific management decisions, such as allowing the passive restoration of plots used for agriculture, introducing rotation regimes with vegetated fallows, or financing the active restoration of certain plots toward priority habitats under the EU Habitats Directive. The key advantage is that these biodiversity improvement estimates are measured annually, allowing for the quantification of biodiversity improvements and providing information on potential biodiversity gains starting from year 0 (the year that the restoration process begins).

Regarding the metrics used to calculate Bv, it is worth noting that the parameter interest was configured to meet two different criteria: (1) conservation status of the species or habitats assessed and (2) amount of information an organism offers about the overall habitat. Criteria (1) are used as a basis for the parameter. However, some biodiversity groups are better studied than others, and while the interest in metrics such as birds can be constructed based on their conservation status, others such as aboveground arthropods may need the support of criteria (2). When the support of criteria (2) is needed, the functionality of the organism is assessed, and the more facts it communicates about the habitat, and the more ecosystemic services it provides, the higher it scores.

For example, an aphid communicates that there are no pesticides present in the ecosystem and that there are green leaves to feed on, whereas a parasitoid wasp communicates that there are flowers producing nectar, other arthropods to parasite for their larvae development, green leaves that feed the aphid, and that no pesticides are present. An aphid provides two pieces of information (in addition to its presence in the ecosystem), while the parasitoid wasp provides four; therefore, the interest in the parasitoid wasp ranks higher. The pieces of information that a taxon provides are directly linked to their ecosystemic function. Taxa with higher requisites on the ecosystem complexity will offer more pieces of information and will thereby be ranked higher.

We believe that the flexibility provided by the definition of interest in the Bv calculation (conservation status and/or amount of information about the habitat and ecosystem services provided by the organism) allows it to be easily adaptable to many socioeconomic and ecological contexts, where priorities regarding the conservation of specific taxa and the objectives pursued may differ greatly [40]. This methodology is adaptable to tropical contexts, where biodiversity loss caused by agriculture is concerning due to its rapid expansion, which threatens some of the most critical and biodiversity-rich areas in the world [41].

One potential limitation identified in the calculation of biodiversity values using the Bv index pertains to the metrics for pollinators and birds. As shown in Table 8 of correlation values between Bv metrics, these two metrics followed unclear patterns and were highly inconsistent with the rest. In the case of pollinators and birds, we believe that measuring these two taxa at the plot level may present challenges, as both are highly mobile and utilize territories much larger than those defined by each habitat. As some authors suggest, the presence of pollinators and birds may be more influenced by landscape-scale factors rather than plot-scale factors [42–45]. The negative correlation between higher Bv values for flora and lower Bv values for pollinators is particularly notable. We believe that this correlation may be due to the sampling method used, specifically the Blue Vane trap. The trap might be significantly more efficient at capturing pollinators in habitats with sparse vegetation or vegetation that is less appealing to pollinators. In contrast, in habitats rich in flora and natural flowers, pollinators may be less attracted to the trap. During field visits, greater pollinator activity was clearly observed in natural and restored habitats compared to agricultural habitats. However, this perceived higher activity and presence of pollinators were not reflected in the sampling results. It is necessary to investigate this distractor effect in future studies to enable reliable comparisons of the pollinator metric. One proposed solution to address the metrics for pollinators and birds is to conduct interannual measurements and consider their effects only at the scale of the entire El Hito Lagoon. In this way, long-term and landscape-level effects of all agro-environmental and restoration actions being carried out can be studied.

Finally, it is accepted that saline environments hinder biodiversity by preventing the establishment of sensitive microorganisms [46] and by limiting water availability for non-adapted flora [47]. However, the protected habitats at El Hito Lagoon are characterized by a composition of halophytic plant species specifically linked to habitats included in the EU Habitats Directive and have been rated higher by the Bv index. On the other hand, historically, cultivation has been avoided in the lower and more saline areas of the lagoon, as agricultural production is greatly reduced by salinity [48]. These factors might explain why areas of lower salinity, and consequently lower pH, are found in agricultural habitats, which have shown the lowest Bv values. In contrast, natural and protected habitats are located in lower elevation areas with higher salinity.

When considering the biodiversity value of the metric soil arthropods isolated, its Bv values are negatively correlated with salinity and pH (−0.37 and −0.26, respectively). It seems that higher salinity and pH values might be negatively affecting the richness of arthropods found in the soil, and therefore negatively affecting the total Bv of high-quality habitats. Due to this factor and the historical preference of agriculture for less saline soils, it would be expected that agricultural plots at the same elevation as the directive habitats would show significant biodiversity gains if ecological restoration was implemented, as seen in habitats such as PP or 1510_R. Future studies will be needed to investigate the potential biodiversity gains in agricultural areas situated at higher elevations within the lagoon.

5. Conclusions

1. This study introduces the Bv index for assessing biodiversity across flora, soil arthropods, aboveground arthropods, pollinators, and birds. The Bv index ranges from 1 to 5, adapts to different ecological and socioeconomic contexts, and avoids setting absolute thresholds for abundance and richness.
2. The highest Bv values were found in habitats protected by the European Habitats Directive and in restoration habitat PP, with values ranging from 2.10 for FL to 2.70 for habitat PP. Agricultural habitats had the lowest Bv values.
3. Multiannual vegetated fallows and legume crops most effectively promote biodiversity in El Hito's agricultural systems. Fodder crops were less beneficial, but further research is needed due to suboptimal measurement conditions.
4. Transitioning from agricultural to ecological restoration habitats would gradually increase biodiversity, with further gains expected as agricultural plots are colonized by species from natural habitats.
5. The proposed method for measuring potential biodiversity gains can help secure funding for agro-environmental and ecological restoration projects aimed at biodiversity recovery in agricultural areas.
6. In El Hito Lagoon, saline areas with higher salinity (1.8–9.1 dS/m) and pH (7.5–8.1) are associated with lower agricultural disturbance, higher Bv values, and unique species. However, soil arthropod richness is negatively correlated with salinity and pH, which can lower total Bv in high-value natural habitats due to parameters not related to their intrinsic quality.

7. Agricultural areas at similar elevations to natural habitats, with lower pH and salinity, have greater potential for restoration to European Directive Habitats and substantial biodiversity gains.

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