



Article Mapping Priority Areas for Connectivity of Yellow-Winged Darter (*Sympetrum flaveolum*, Linnaeus 1758) under Climate Change

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Abstract: The yellow-winged darter (*Sympetrum flaveolum* Linnaeus, 1758, Odonata), which is associated with high mountain areas, can be considered a flagship species. Due to climate change, its natural range will be negatively affected. In this study, we propose global potential distributions for this species up to the year 2100, considering four time periods (2021–2040, 2041–2060, 2061–2080, and 2081–2100) and three shared socioeconomic pathways (optimistic—SSP245, middle of the road—SSP370, and worst—SSP585), by using an ecological niche model to produce two sets of distribution models (80% to 100% and 60% to 100%). It is foreseen that in the worst of the considered climate scenario (SSP585–2100 year), the distribution of this species could be reduced by almost half, which could pose a risk for the species and provoke the shift from vulnerable to endangered. An analysis of connectivity has also been carried out for all the studied scenarios by applying the MSPA and PC indices, showing that the core habitat of this species will become more important, which is consistent with the decrease in the distribution range. Over time, the importance of the most valuable connectors will increase, implying a greater risk of some populations becoming isolated.

Keywords: ecological connectivity; climate change; MSPA; ecological niche modeling; PC index; dragonfly; Odonata

1. Introduction

Climate change is a major concern of the scientific community [1–3]. The consequences of this global impact are manifold; among them, it is likely to have a significant impact on different levels of biodiversity [4–9] and, particularly, on freshwater biodiversity [10]. In the last decade of the 20th century and the first two decades of the 21st century, numerous and diverse studies have been carried out to predict climate change's effects on ecological niches and biodiversity. Thus, changes in the phenology and life cycles of numerous species have been documented [11,12], as well as alterations in their range that may consist of expansions, reductions, or migratory shifts [5,13,14]. In the most extreme situations, climate change can even lead to the extinction of the species [15].

The order Odonata (dragonflies and damselflies) is a group of insects with ideal characteristics and life cycles to be used as bioindicators of ecosystem quality and, thus,



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Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). in climate change research [16,17]. They are distributed in freshwater habitats with very specific conditions, and their populations are very sensitive to alterations in environmental conditions such as fluctuations in the water table or flow, air temperature, concentration of pollutants in the water, and water physicochemical characteristics such as electrical conductivity, pH, dissolved oxygen and temperature [18,19].

In this study, the global potential distribution of an odonate species, the yellowwinged darter (*Sympetrum flaveolum* L.), was investigated. It is a dragonfly belonging to the suborder Anisoptera, widely distributed throughout the Palearctic region from Japan to Portugal [20–22]. In southern Europe, and particularly in the Iberian Peninsula, the southwestern limit of its natural range, populations are fragmented and generally associated with mountainous areas. Lowland populations are short-lived and, in most cases, die out after a few years (up to 5–6 years). This can be thought of as an "influx model pattern" followed by decline and disappearance. [20,23–25]. This species also occurs in the southern half of Fennoscandia [26].

The habitat of *S. flaveolum* consists of shallow water areas with abundant vegetation that are usually dry in summer and are neither too eutrophic nor shaded [20,22,25,27,28]. The aforementioned high mountain distribution and its habitat, associated with aquatic environments, make this species particularly susceptible to climate change. In this regard, Warren et al. [29] suggest that a 2 °C increase in average temperature, the maximum limit set at the Paris Summit [30], would make the current areas of distribution unsuitable. Paradoxically, however, a reduction in the depth of high mountain wetlands could improve the status of populations [31]. Therefore, it is foreseeable that the increase in mean temperature brought about by climate change and variations in water tables will lead to significant changes in the distribution of *S. flaveolum*.

Though globally listed as the Least Concern in the IUCN Red List, *S. flaveolum* is considered Vulnerable in some countries, such as Spain [20] or Italy. This fact means that, at least in some peripheric areas of its natural range, it faces a high risk of shifting to Endangered status and, finally, becoming extinct. Likewise, its populations are severely fragmented, and a decrease in the area of distribution and the extent and/or quality of habitat has been observed or inferred [32].

The stenosis of this species, its inclusion in the vulnerable category in the IUCN Red List for some countries, and the need to act on aquatic ecosystems to ensure its conservation justifies the interest in assessing the current status of *S. flaveolum* populations and predicting future scenarios under the pressure of climate change. Likewise, once the evolution of this species is known, it will be possible to infer that of other species with similar ecological values. In that sense, it is urgent to identify effective conservation strategies for protecting the biodiversity of freshwater ecosystems in the climate change scenario in which we are immersed [33].

Thus, in order to predict future scenarios, it is necessary to have a better knowledge of, among other factors, the connectivity between populations, which, according to Bush et al. [34], is a function of the dispersal capacity of the species and the availability of climatic refuge. In this regard, it is worth bearing in mind that *S. flaveolum* is a migratory species [21,35], although it does not present a high dispersal capacity [36].

The present study aims to develop better knowledge of the future situation of *S. flaveolum*, particularly: (i) to predict the potential distribution area of this species in different future scenarios of climate change; and (ii) to study the connectivity within this potential distribution for all scenarios and with two probabilities of appearance (from 60% to 100% and from 80% to 100%) clustering by terrestrial ecoregions with similar connectivity, in order to inform potential conservation measures for this species, which will also contribute to the conservation of other species living in the same habitat.

2. Material and Method

2.1. Species

The yellow-winged darter [Sympetrum flaveolum (Linnaeus, 1758)] is distributed throughout most of Eurasia from Europe to mid and northern China [37,38]. It occasionally migrates to the United Kingdom [38]. The species is bred in a wide range of stagnant waters. It could be found in peat bogs, waterbodies, garden pools, wetland pools, oxbow lakes, quarry pools, even fishponds, and artificial canals. Adult dragonflies are found from late June to October and peak in August. The nymphs succeed in stagnant water, small, shallow, and rich in vegetation. They are usually found in peat bogs, flooded meadows, and marshy areas, often at higher altitudes [38,39]. The species is a prominent predator and has an important role in the food webs of high-altitude lakes. Therefore, its disappearance would lead to major changes in these food webs [38,39].

2.2. Study Area

The study area encompassed the present natural range of *S. flaveolum* and areas where the species could potentially live in the future in Europe and non-tropical Asia. For this study, we hypothesized that all this area is freely accessible to *S. flaveolum* currently and in the future.

2.3. Occurrence Data

Future predictions for *S. flaveolum* were made using all available data in the Global Biodiversity Information Facility, from which a total of 19,997 occurrence records were acquired (GBIF 2022: 19,901 records, www.gbif.org (accessed on 1 August 2022), and 96 capture data). These records were verified to be accurate using ArcGIS and georeferenced using the WGS84 coordinate system (v10.7, ESRI, Redlands, CA, USA). We used the tool spThin ver. 0.2.0 [40] to draw a 5-km buffer area around each occurrence record to reduce sampling error that could overestimate the anticipated distribution [39] and to reduce spatial autocorrelation [41,42]. We thinned a total of 19,997 occurrence records to 4837 to represent its presence for each grid cell. We simulated *S. flaveolum's* potential range for both present and future situations [43]. We identified the research area where records of the species exist in order to predict the species' future forecasts. The study region was shielded from climate influences.

Climate Data

The WorldClim v2.1 database ([44]; www.worldclim.org), with a geographical resolution of 2.5' (about 4.7 km), provided the climatic data used in this investigation. The various WorldClim variables were derived from monthly averages of precipitation and temperature for the years 1970 to 2000. The modeling process made use of fifteen recent bioclimatic variables. The removal of four variables (BIO8, BIO9, BIO18, and BIO19) where some spatial artifacts had been found in earlier studies (such as [45,46]) was done.

Using the 'usdm' package [47], we removed the variance inflation factor higher than 5 and used a correlation threshold of 0.75 to lessen the potentially harmful effects that could arise from multicollinearity and high correlation (r>0.75 or -0.75) among the bioclimatic variables [48–52]. The input variables used in this study were BIO2: mean diurnal range (mean of monthly [max temp—min temp]); BIO4: temperature seasonality (standard deviation ×100), BIO5: maximum temperature of warmest month; BIO13 = precipitation of wettest month; BIO14 = precipitation of driest month, and BIO15 = precipitation seasonality (coefficient of variation). For the analysis of the results, two distribution probability ranges (60–100 % and 80–100 %) were considered.

The fit models were projected to five different global circulation models (GCMs): BCC-CSM2-MR [53], CNRM-CM6-1 [54], CNRM-ESM2-1 [55], CanESM5 [56], and MIROC6 [57] to account for an appropriate level of uncertainty in the climate model projections [58]. Future data from the 6th Climate Model Intercomparison Project (CMIP6, www.wcrp-climate.org/wgcm-cmip/wgcm-cmip6) with three shared socioeconomic pathways were acquired

for the periods 2021–2040, 2041–2060, 2061–2080, and 2081–2100. (SSPs) (optimistic—SSP245, middle of the road—SSP370, and worst—SSP585).

2.4. Methodology

Phase 1. Sampling and data collection on the distribution of the target species

To know the global distribution of *Sympetrum flaveolum*, location points were compiled using the Global Biodiversity Information Facility database. For climatic data, the climate models of worldclim were used.

Phase 2. Ecological niche modeling

Using an ensemble method in the sdm package [40] in the R v3.6.3 environment, we created ecological niche models to project the current and future habitat suitability of *S. flaveolum*. The generalized linear model (GLM; [41], boosted regression trees (BRT) [42], random forests (RF) [43], and maximum entropy (MaxEnt) [44] with 10,000 randomly selected pseudo-absences were five algorithms that we implemented using various approaches. According to Naimi and Araújo [41], we used the sdm package's usual parameterization to run all the algorithms. The small sample size necessitated the use of the subsample and bootstrapping resampling methods [45], which were divided into subsets of 70-30% for model calibration and testing. A true skill statistic (TSS) and the area under the receiver operating characteristic (AUC) were calculated for each model, and each model was run ten times. To assess the species' adaptability to its current environment at the time of analysis, we created 50 distinct models (5 algorithms \times 1 resampling method \times 10 replications). To create ensemble models for each scenario, we chose the models with TSS > 0.7and AUC > 0.9 as the best. The best models were assembled using the mean of predicted presence-absence values technique, which involves converting the expected probability of occurrences to presence-absence using a threshold before averaging. Following that, the chosen models were projected into current and future circumstances. As a result, we implemented 60 projections (5 GCMs, 3 SSPs, and 4 time periods) and generated ensemble rasters for the GCM scenarios and periods. The outputs indicate habitat suitability on a scale of 0 (unsuitable) to 1 (suitable) (suitable). We converted the ensemble suitability models into binary maps of acceptable environmental conditions and used them by maximizing the sum of sensitivity and specificity (maxSSS), as Liu et al. [46] proposed. The RasterVis package was used to illustrate the results [48].

Phase 3. Comparison of distribution areas

In this phase, changes in the distribution area between the current situation and the expected situation for all the proposed scenarios were analyzed.

Phase 4. Calculation of connectivity using the MSPA and the PC index

This phase aims to compare connectivity by calculating the morphological spatial pattern analysis (MSPA) [47], which measures structural connectivity through the number of connecting elements, and the probability of connectivity index (PC) [47], which measures the importance of each of the connection elements previously analyzed, for all climate scenarios and with the two probability ranges, resulting in a total of 26 possible situations.

2.5. Statistical Analysis

In order to group the terrestrial ecoregions in clusters with similar connectivity (number of yellow-winged darter links), we used principal component analysis (PCA) [59]. First, we developed a PCA analysis with the number of links from terrestrial ecoregions obtained in the previous analysis according to the current situation and climate change scenarios: optimistic—SSP245, middle of the road—SSP370, and worst—SSP585 for 2040, 2060, 2080 and 2100. Then, we classified all terrestrial ecoregions (ordered by PCA) according to their similar connectivity across the different climate change scenarios. The hierarchical classification was performed using Ward's criterion on the selected principal components [60].

R. 4.2.1 (R Development Core Team 2022) with the packages "FactoMineR" [61], "factoextra" [62], and "vegan" [63] were used for data processing and statistics.

3. Results

Overall, our ecological niche models (ENMs) have an average AUC of 0.936 (SD = 0.036) and an average TSS of 0.775 (SD = 0.115). Our ENM for present-day conditions indicates that the habitats suitable for *S. flaveolum* spread across most of Europe, western Siberia, northern Anatolia, the Caucasus, the Himalayas, northern Japan, Sakhalin, and Kamchatka Peninsula (Figure 1). According to the occurrence record, it is also quite frequent in other areas where our model indicates a low probability of occurrence, such as Korea or Mongolia.



Figure 1. Average prediction of climate habitat suitability maps for *Sympetrum flaveolum* projected to the present day. Red dots show occurrence records. The probability of occurrence ranges from 0 (dark purple, low probability) to 1 (yellow, highest probability).

Our results show that the habitat suitability of the species is explained by temperature seasonality (BIO4, 29%), precipitation of the driest month (BIO14, 22%), precipitation seasonality (BIO15, 19%), the maximum temperature of the warmest month (BIO5, 19%), mean diurnal range (BIO2, 9%), and precipitation of wettest month (BIO13, 8%). They also predict that the suitable habitats for this species will shift towards the north and will disappear up to 2100, under future climate scenarios, in southern Europe, Anatolia, the Caucasus, the southernmost area of western Siberia, and Japan, thus comprising all the southern limit of its present range (Figure 2). At the same time, some northern areas that are currently unsuitable for *S. flaveolum* will become suitable, as would be the case in northwestern Siberia and Chukotka.

Tables 1 and 2 show the changes in the potential distribution of *Sympetrum flaveolum* for the different study scenarios. For both distributions (80–100% and 60–100%), the potential area will decrease until it reaches 60.93% and 63.4%, respectively, for the year 2100 in the worst possible scenario. With scenario SSP245, affection would be initially much lower since its distribution would be reduced, in the year 2080, by 3% (80–100%) and just 0.7% (60–100%), though by the year 2100, affection will increase, with distribution been reduced to 91.81% (80–100%) and 93.88% (60–100%). In an intermediate position is scenario SSP370, the only scenario in which the area would decrease in all years and in which the area in the year 2100 would decrease by a quarter for both distributions.



Figure 2. Average prediction of climate habitat suitability maps for *Sympetrum flaveolum* under future climate scenarios. Average projections are presented for each of four time periods (2021–2040, 2041–2060, 2061–2080, and 2081–2100) and three shared socioeconomic pathways (optimistic—SSP245, middle of the road—SSP370 and worst—SSP585). The probability of occurrence ranges from 0 (dark purple, low probability) to 1 (yellow, highest probability).

Area (km²) % Scenario Present-time 31,105,874 100 SSP245 32,589,949 104.77 2040 SSP370 29,751,246 95.65 **SSP585** 31,792,341 102.21 97.85 SSP245 30,437,912 27,751,750 89.22 2060 SSP370 **SSP585** 27,491,675 88.38 97.77 SSP245 30,411,851 79.84 2080 SSP370 24,836,400 SSP585 23,258,831 74.77 SSP245 28,557,897 91.81 2100 SSP370 23,331,819 75.01 SSP585 18,952,658 60.93

Table 1. Evolution of the estimated potential distribution area of *Sympetrum flaveolum* in absolute and relative values (Present—2100). 80–100%.

Table 2. Evolution of the estimated potential distribution area of *Sympetrum flaveolum* in absolute and relative values (Present—2100). 60–100%.

Sce	nario	Area (km ²)	%
Prese	nt-time	32,805,232	100.00
	SSP245	34,373,533	104.78
2040	SSP370	32,005,322	97.56
	SSP585	33,772,939	102.95

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Sce	nario	Area (km ²)	%
	SSP245	32,649,735	99.53
2060	SSP370	30,047,687	91.59
	SSP585	29,845,603	90.98
	SSP245	32,575,874	99.30
2080	SSP370	27,262,806	83.11
	SSP585	25,114,100	76.56
	SSP245	30,797,932	93.88
2100	SSP370	25,166,930	76.72
	SSP585	20,797,436	63.40

Table 2. Cont.

3.1. MSPA Index

The distribution of the components of the MSPA, according to the results provided by Guidos software, is shown in Figure 3 for the current distribution and in Appendices A.1 and A.2 for the potential distribution under the different considered scenarios. Comparing these situations, it is found that, in all the cases, the area occupied by cores decreases notably, throughout the study period, especially in peripheral zones, except in the Russian Far East. Simultaneously, there is an increase in the number of islets in southern areas currently occupied by this species and a significantly higher number of bridges.



Figure 3. Results of the MSPA analysis for the current situation for distributions 80–100% (**up**) and 60–100% (**down**).

It should be noted that all possibilities show an increase in the number of bridges compared to the current distribution.

As these bridges link habitat patches and serve as vital functional dispersal corridors, their gradual loss until 2100 has a detrimental impact on the maintenance of functional connectedness [64,65].

The critical areas for both distributions have also been located and are shown in Appendices A.3 and A.4.

In addition, the PCA revealed an ordination of terrestrial ecoregions according to the different climate change scenarios considered in this study (Figure 4). The two first principal components (dimensions) explained more than 85% of the cumulative variance for both distributions, 60–100% and 80–100% (Figure 4i,ii, respectively). Finally, using the PCA hierarchical classification, we classified the ecoregions into four clusters with similar connectivity across the different scenarios of climate change and by distribution (60–100% Figure 4ii and 60–100% Figure 4iv). Most of the ecoregions were included in clusters 1 and 2 (Figure 4ii,iv; Appendices A.5 and A.6). However, Alps Conifer and mixed forests were exclusively included in cluster 4 for both distributions (Appendices A.5 and A.6), having different connectivity (number of links) that other terrestrial ecoregions by the different scenarios of climate change. Cluster 3 also included a few terrestrial ecoregions: Bering Tundra, Scandinavian Montane Birch Forest and Grasslands, and West Siberian Taiga. The tables with the calculation variables for the different clusters can be found in Appendices A.7 and A.8.



Figure 4. Connectivity terrestrial ecoregion ordination and cluster classification. Principal component analysis ((i) for 60–100% distribution and (iii) for 80–100% distribution) and hierarchical classification ((ii) for 60–100% distribution and (iv) for 80–100% distribution) focusing on link data numbers from the terrestrial ecoregions according to three shared socioeconomic pathways (optimistic—SSP245, middle of the road—SSP370, and worst—SSP585 in years 2040, 2060, 2080, and 2100. The symbols correspond to terrestrial ecoregions for points and thirteen climate change scenarios for grey arrows (i) for 60–100% distribution and (iii) for 80–100% distribution) and to terrestrial ecoregions grouped in four clusters (with different colors in the graph) with similar connectivity (ii) for 60–100% distribution and (iv) for 80–100% distribution). PCA1 and PCA2 explained 74.2% and 11.3% of the variance for 60–100% distribution (i), respectively, and PCA1 and PCA2 explained 78.6% and 7.3% of the variance for 80–100% distribution (iv), respectively.

3.2. PC Index

The study of the dPC index ranks the nodes and links on the map according to how much they contribute to connectivity [66]. As can be observed in Appendices A.1 and A.2, since core regions are usually so huge that we cannot use them to support management

methods for boosting connectivity, we are focusing on corridors, which are also the most important structures in terms of connectivity [64–67].

Tables 3 and 4 show the variation in the importance of connectors in the different considered scenarios and throughout the study period. According to these data, in the 80–100% distribution, the number of connectors increases in the first decades of the study period, reaching a maximum for SSP535 by the year 2040 (7370 connectors) and for SSP245 (6048 connectors) and SSP370 (6873 connectors) by the year 2060. Later on, the number of connectors decreases, reaching the minimum by the year 2080 for SSP245 (5808 connectors) and by the year 2100 for SSP370 (4281 connectors) and SSP535 (3499 connectors). In the 60–100% distribution, a similar pattern was present, with a maximum in the number of connectors by the year 2040 (SSP370 and SSP535) and 2060 (SSP245) and a minimum in 2100 for the three scenarios.

Sce	nario	PC Sum Links	Max	Number	Median
Prese	nt-time	54.97824	0.588259	5136	0.005591076
	SSP245	7.476563	0.073731	5919	0.002369475
2040	SSP370	16.674742	0.161898	5732	0.004110193
	SSP585	4.194349	0.231289	7370	0.000711398
	SSP245	115.543238	0.843213	6048	0.015330767
2060	SSP370	13.302049	0.0956	6873	0.02986639
	SSP585	178.388911	0.497718	6464	0.002514614
	SSP245	63.954432	0.834766	5808	0.008266973
2080	SSP370	6.21363	0.268315	5414	0.011441741
	SSP585	27.462305	2.307007	5004	0.002787564
	SSP245	195.926497	0.509482	5907	0.005591104
2100	SSP370	1.52086	0.038689	4281	0.133939254
	SSP585	142.119542	10.481495	3499	0.001183118

Table 3. Variation in the importance of connectors with the 80–100% distribution.

Table 4. Variation in the importance of connectors with the 60–100% distribution.

Sce	nario	PC Sum links	Max	Number	Median
Prese	nt-time	29.733343	0.678515	5318	0.01070449
	SSP245	15.873111	0.168677	6699	0.00126315
2040	SSP370	28.894654	0.168677	7030	0.00290906
	SSP585	4.968406	0.162946	6984	0.00056911
	SSP245	105.153733	1.078804	6859	0.01910437
2060	SSP370	209.034867	0.72389	6999	0.00193541
	SSP585	17.448906	0.158492	6939	0.02759729
	SSP245	53.900665	0.758437	6520	0.01101144
2080	SSP370	71.11042	0.564638	6215	0.0011477
	SSP585	13.438845	3.247807	4821	0.00548807
	SSP245	33.691993	0.244705	6026	0.03316853
2100	SSP370	633.264791	10.453527	4728	0.00035526
	SSP585	4.544358	0.143843	3841	0.04061719

Usually, the maximum value of ecological corridors varied between 0.073731 (SSP245, the year 2040) and 2.307007 (SSP585, the year 2080) with the 80–100% distribution and between 0.143843 (SSP585, the year 2100) and 3.247807 (SSP585, the year 2080) with the 60–100% distribution. In the year 2100, however, a value of 10.48 is found for the maximum value of ecological corridors for the 80%–100% distribution for scenario SSP585, and a very similar value is found for the same year 2100 in the 60%–100% distribution for scenario SSP370 (10.45), suggesting that in 2100, with the reduction in surface area and

potential isolation of the cores, the most crucial connectors assume a greater value to prevent fragmentation.

Analyzing the global set of connectors, in the 80–100% distribution, the value of importance is multiplied by almost four in scenario SSP245 for the year 2100. For the 60–100% distribution, this increase occurs for scenario SSP370, which corresponds to a 2100% increase compared to the importance of the current scenario. Such high increases indicate that the fragmentation that will occur in the different scenarios is maximum, so the importance of the connectors is increased to reduce the possible fragmentation caused by climate change.

In order to determine the PC index in smaller areas, PC values have been calculated for ecoregions in which there is potential distribution. Figure 5 shows, as an example, the evolution of the PC indices for the ecoregions and the different clusters previously obtained.



Figure 5. Evolution of pc values by ecoregion for scenario 585 in the distribution from 80% to 100%.

Maps of all the index values calculated for the different scenarios and distributions are shown in Appendices A.5 and A.6.

4. Discussion

While assessing connections between habitats in a landscape matrix, changes that may occur in land cover over time and how species may spread against bioclimatic variables are often ignored [49–51,68]. However, the responses of species to global climate change have been accepted as the most important environmental factor that determines the main characteristics of habitats and their distribution areas [53,54]. In this context, understanding the direction and magnitude of species responses is important for species conservation and sustainability [55,56]. Since climate change differentiates the bioclimatic demands of species under optimal conditions, it also causes changes in their geographical distribution [57,68–71]. This change is widely linked to increased temperatures and decreased precipitation during the growing season [72]. Every 1 °C change in temperature moves ecological regions around the world about 160 km. Thus, for example, if the climate warms by 4 °C in the next century, species in the northern hemisphere may need to move 500 km north (or 500 m higher) [73]. Many studies that refer to the impact of climate

change on species have investigated the effects of global temperature rise, confirming that species will migrate to the poles (higher latitudes) and higher altitudes as a result [74]. In addition, it has been predicted that the geographic ranges of species will expand, shift or contract [75]. While some studies indicate that certain species may become stronger against climate resistance in the future, it is predicted that some will experience habitat loss, which will negatively affect biodiversity [76–78]. Furthermore, it has been reported that rapid climate change may put pressure on relict species and cause species extinction [78–80]. Climate-related variables such as temperature and precipitation are important for the effects on species survival, distribution, and other characteristics, as well as for the species composition of natural ecosystems and the future of terrestrial ecosystems [81,82].

Our study is consistent with the aforementioned studies, suggesting that the natural range of *S. flaveolum* will reduce significantly in all the proposed scenarios, with this loss being particularly large (up to 40%) in the SSP585 scenario. Furthermore, as has been predicted in other species, the distribution area will also shift northward. Consequently, this species will virtually disappear from the Mediterranean Basin and other southern locations and will spread to northern areas of the Eurasian continent.

The results of the MSPA analysis and PC index showed a loss of connectivity in *S. flaveolum* patches, particularly in its southernmost range. Lack of landscape connectivity can isolate habitat patches that affect gene flow, among other ecological processes. Greater connectivity increases the ability of species to migrate to new regions in the face of climate change and reduces the likelihood of extinction. For this reason, greater connectivity may increase the chances of many organisms surviving under changing climatic conditions. Consequently, this loss of connectivity will negatively affect the populations of the yellow-winged darter and will pose a serious threat to the survival of this species in southern Eurasia.

Due to the strong dispersal capacity of dragonflies in general, changes in the current climate and resource availability primarily affect how they are distributed. This is because dragonflies can track changing climatic and environmental circumstances owing to their flying ability. Olsen et al. [83] stated that dragonflies are often influenced by habitat specialization (species vulnerability to habitat loss and fragmentation [84] or linked dispersal limitation. Previous studies confirm this statement and highlight that extreme habitat specialization can be more effective than dispersal ability, particularly for permanent running water species. The differences between nodes and links in this study can be a reason for either extreme habitat specialization or reduced dispersal ability.

Mountain chains in the European topography can act as barriers for odonate species; therefore, wide river plains can be regarded as corridors. This can be understood from the maps produced in this study. The northern side of the Iberian Peninsula or northern Europe is highly affected by climate change making these areas critical. Geostatistical analysis of the data from the critical detection areas supports this.

We discover that species in permanent water habitats, including both rushing and standing waters, move north to a far lesser extent than those that are adapted to seasonally dry habitats. This suggests that transient waters support the diversity of dragonflies and serve as stepping stones for the spread of generalist species [81]. In comparison to species suited to permanent flowing water environments, species adapted to permanent standing water or transient water habitats, which are less persistent in time and space, spread more effectively [85].

From the point of view of potential distribution, and based on this study, it is more advisable to use the 60% to 100% range since the connectivity shown by this distribution is included within the 80% to 100% range, and the discontinuous zones show where the fragmentation risks really are.

5. Conclusions

Experimental studies that use ecological niche modeling predict significant changes in species distributions in response to climate change. As habitat fragmentation can hinder

species range changes, maintaining wildlife corridors may be of increasing importance in enhancing climate resilience for species survival. Therefore, identifying degrees of connectivity between habitats play a vital role in adapting to changing climatic conditions.

In this study, current, potential, and future connectivity changes in *S. flaveolum* were predicted by combining an ecological niche model and an ecological connectivity approach. Besides determining suitable habitats for the species, we identified priority areas for connectivity relevant to the sustainability of *S. flaveolum*. Our approach provides a robust and practical tool to optimize biodiversity conservation objectively. Further study can integrate land use/land cover changes into our method and make a broader interpretation of the species distribution.

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Appendix A

Appendix A.1. MSPA Analysis under Different Climate Scenarios (60–100%)







80°0'0"E

100°0'0"E

120°0'0"E

140°0'0"E

160°0'0"E

180°0'0"





2021-2040 SSP 370

0°0'0"

20°0'0"E

40°0'0"E

60°0'0"E











2061-2080 SSP 370

2080-2100 SSP 370

2041-2060 SSP 585



2021-2040 SSP 585



0°0'0" 20°0'0"E 40°0'0"E 60°0'0"E 80°0'0"E 100°0'0"E 120°0'0"E 140°0'0"E 160°0'0"E 180°0'0"



0°0'0" 20°0'0"E 40°0'0"E 60°0'0"E 80°0'0"E 100°0'0"E 120°0'0" 2061-2080 SSP 585





Appendix A.2. MSPA Analysis under Different Climate Scenarios (80–100%)



2041-2060 SSP 245



2061-2080 SSP 245







2021-2040 SSP 370

70°0'0"N

60°0'0"N

50°0'0"N

40°0'0"N 30°0'0"N

70°0'0"N

60°0'0"N 50°0'0"N

40°0'0"N 30°0'0"N

70°0'0"N 60°0'0"N 50°0'0"N 40°0'0"N 30°0'0"N

2061-2080 SSP 370

2041-2060 SSP 370

0°0'0"

0°0'0"

0°0'0"

20°0'0"E

20°0'0"E

20°0'0"E

40°0'0"E

40°0'0"E

40°0'0"E

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100°0'0"E

100°0'0"E

100°0'0"E

120°0'0"E

120°0'0"E

120°0'0"E

140°0'0"E

140°0'0"E

140°0'0"E



1.000 2.000

1.000 2.000

.000 2.000

160°0'0"E

160°0'0"E

160°0'0"E

Kilometers

180°0'0"

180°0'0"

180°0'0"







2041-2060 SSP 585









Appendix A.3. Critical Areas for Connectivity under Different Climate Scenarios (60–100%)









Appendix A.4. Critical Areas for Connectivity under Different Climate Scenarios (80–100%)







Appendix A.5. MSPA Analysis under Different Climate Scenarios (60–100%)









Appendix A.6. MSPA Analysis under Different Climate Scenarios (80–100%)







ECO_NAME	Terrestrial Ecoregion Clusters	C1_ 2020	C245_2040	C245_2060	C245_2080	C245_2100	C370_2040	C370_2060	C370_2080	C370_2100	C585_2040	C585_2060	C585_2080	C585_2100
Aegean And Western Turkey Sclerophyllous And Mixed	1	53	3	5	0	0	2	0	0	0	2	0	0	0
Alps Conifer And Mixed Forests	4	0	466	601	674	836	671	747	867	832	526	812	949	810
Altai Alpine Meadow And	2	168	80	112	60	41	155	51	27	93	61	83	84	85
Altai Montane Forest And Forest	2	132	33	80	61	88	71	64	48	60	105	78	46	35
Steppe Altai Steppe And Semi-Desert	1	40	13	0	13	14	16	2	3	13	3	10	0	7
Anatolian Conifer And Deciduous Mixed Forests	1	124	25	2	4	8	0	4	10	2	9	4	2	0
Appenine Deciduous Montane	1	5	57	39	44	25	60	22	0	0	47	28	5	0
Atlantic Mixed Forests	1	10	38	95	26	29	38	58	77	8	20	75	16	55
Azerbaijan Shrub Desert And	1	0	0	5	2	0	0	0	0	0	4	0	0	0
Balkan Mixed Forests	1	78	119	77	59	22	113	51	26	0	121	46	10	0
Baltic Mixed Forests	1	31	43	38	38	36	37	37	38	54	35	35	39	37
Baluchistan Xeric Woodlands	1	3	0	0	0	0	0	0	0	0	2	2	0	0
Bering Tundra	3	158	527	526	289	174	369	584	250	37	619	446	55	48
Caledon Conifer Forests	1	34	9	0	0	10	4	11	9	0	23	9	12	5
Cantabrian Mixed Forests	1	0	20	0	0	6	20	28	97	128	12	58	88	83
Carpathian Montane Forests	1	0	6	16	18	84	1	102	157	138	5	91	77	44
Caspian Hyrcanian Mixed Forests	1	0	6	0	2	0	0	0	0	0	0	0	0	0
Caucasus Mixed Forests	2	183	79	87	106	101	53	39	159	35	63	46	71	60
Centrel Anatolian Storma And	2	79	195	149	199	175	187	75	158	60	96	186	117	83
Woodlands	1	23	0	0	0	0	0	0	0	0	0	0	0	0
Central European Mixed Forests	2	0	22	20	0	225	25	211	197	146	62	88	219	43
Cherskii-Kolyma Mountain Tundra	1	31	32	135	4	16	0	122	30	0	90	103	0	17
Chukchi Peninsula Tundra	2	0	0	42	101	160	0	224	85	162	136	94	205	57
Corsican Montane Broadleat And Mixed Forests	1	0	32	40	35	31	32	31	36	0	28	31	24	0
Crimean Submediterranean Forest Complex	1	6	5	19	9	8	13	9	0	0	16	4	3	0
Dinaric Mountains Mixed Forests	2	23	61	121	158	166	55	190	107	0	10	155	52	0
East European Forest Steppe	2	1	89	252	279	120	229	271	40	15	129	128	22	0
East Siberian Taiga	2	150	107	157	329	212	137	60	145	97	452	229	48	35
Eastern Anatolian Deciduous Forests	1	1	26	0	0	0	37	0	0	0	0	0	0	0
Eastern Anatolian Montane Steppe	1	84	34	18	12	6	44	28	8	14	15	13	4	0
Elburz Range Forest Steppe	1	0	6	0	0	0	0	0	0	0	0	0	0	0
Emin Valley Steppe	1	Ő	39	18	39	55	õ	ĩ	õ	11	õ	30	14	18
Euxine-Colchic Broadleaf Forests	1	8	62	41	69	44	60	99	63	0	56	64	29	0

Appendix A.7. Cluster Calculation (60–100%)

ECO_NAME	Terrestrial Ecoregion Clusters	C1_ 2020	C245_2040	C245_2060	C245_2080	C245_2100	C370_2040	C370_2060	C370_2080	C370_2100	C585_2040	C585_2060	C585_2080	C585_2100
Gissaro-Alai Open Woodlands	2	278	327	263	201	175	339	237	118	92	323	199	75	46
Himalayan Subtropical Pine Forests	1	19	8	12	0	0	8	9	0	0	9	0	0	0
Hindu Kush Alpine Meadow	1	0	0	0	0	0	0	15	0	0	25	13	15	11
Hokkaido Deciduous Forests	1	3	64	2	31	25	25	33	37	21	60	0	15	8
Hokkaido Montane Conifer	1	22	12	2	F	10	2	26	47	2	26	0	0	0
Forests	1	25	15	2	3	12	5	20	4/	5	30	0	0	0
Honshu Alpine Conifer Forests	1	7	4	9	8	16	0	0	0	0	19	3	0	0
Iberian Conifer Forests	1	7	21	0	0	0	22	0	0	0	18	0	0	0
Iberian Sclerophyllous And	1	36	0	0	0	0	0	0	0	0	0	0	0	0
Semi-Deciduous Forests					-	-		-	-	-	-	-	~	~
Illyrian Deciduous Forests	1	123	11	22	0	0	21	0	0	0	5	0	0	0
Italian Scierophyllous And	1	62	43	5	12	13	36	17	0	0	50	15	0	0
Semi-Deciduous Forests	1	22	0	0	4	F	ø	0	0	4	0	22	0	0
Kamchatka Mountain Tundra	1	25	0	0	4	5	0	0	0	4	0	32	0	0
And Forest Tundra	2	123	339	46	31	0	359	0	0	0	44	10	0	0
Kamchatka-Kurile Meadows And														
Sparse Forests	1	24	64	32	30	34	246	42	10	21	74	38	12	18
Kamchatka-Kurile Taiga	1	7	0	0	0	0	5	0	0	0	0	0	0	0
Karakoram-West Tibetan Plateau	2	11	FO	124	155	00	42	120	156	115	50	06	102	70
Alpine Steppe	2	11	50	154	155	99	42	129	136	115	32	90	105	70
Kazakh Forest Steppe	2	146	68	46	84	86	96	142	17	23	144	45	7	13
Kazakh Upland	1	52	3	44	0	0	22	15	0	0	48	0	0	0
Kola Peninsula Tundra	1	0	0	0	0	0	0	0	0	0	6	0	0	0
Kopet Dag Woodlands And	1	4	0	0	0	0	0	0	0	0	0	0	0	0
Forest Steppe	1	0	0	0	0	0	0	0	1	0	0	(0	0
Lake: Palearctic	1	8	0	0	0	0	0	0	1	0	0	6	0	0
Forosts	1	110	46	42	52	28	24	1	0	0	74	14	0	0
North Atlantic Moist Mixed														
Forests	1	0	0	0	12	0	0	0	0	0	0	0	0	0
Northeast Siberian Taiga	2	21	383	118	23	36	103	86	7	0	181	89	0	4
Northeastern Spain And														
Southern France Mediterranean	1	25	15	47	41	17	0	8	0	1	30	14	0	5
Forests														
Northern Anatolian Conifer And	1	82	50	49	53	47	71	65	53	8	36	46	18	21
Deciduous Forests	1	02	50	1)	00	-17	71	05	55	0	50	40	10	21
Northwest Iberian Montane	1	32	14	44	21	0	48	3	0	0	12	0	0	0
Forests														
Northwest Russian-Novaya	1	35	86	74	138	71	95	8	0	0	41	9	15	37
Northurstern Himalayan Almina														
Shrub And Mondows	2	248	236	188	126	86	217	223	154	102	271	141	142	96
Nuijang Langcang Corge Alpine														
Conjfer And Mixed Forests	1	0	0	0	0	0	0	0	0	0	0	10	0	0
Okhotsk-Manchurian Taiga	2	44	128	108	97	61	131	45	103	94	199	220	85	165
Pamir Alpine Desert And Tundra	2	108	202	241	205	193	225	244	227	275	169	216	94	188
Pannonian Mixed Forests	1	0	110	126	78	15	56	53	0	0	68	52	18	1
Paropamisus Xeric Woodlands	1	0	0	0	0	0	0	4	11	27	0	0	11	28

ECO_NAME	Terrestrial Ecoregion Clusters	C1_ 2020	C245_2040	C245_2060	C245_2080	C245_2100	C370_2040	C370_2060	C370_2080	C370_2100	C585_2040	C585_2060	C585_2080	C585_2100
Pindus Mountains Mixed Forests	1	23	60	66	74	0	77	9	0	0	51	35	0	0
Po Basin Mixed Forests	1	0	1	0	0	0	1	0	0	0	0	0	0	0
Pontic Steppe	1	163	93	27	4	13	0	4	16	0	12	0	0	0
Forests	1	4	0	40	0	82	0	0	34	149	0	24	48	55
Rock And Ice: Palearctic	1	2	10	16	41	37	10	40	51	113	6	45	51	147
Rodope Montane Mixed Forests	1	0	23	39	50	10	22	27	0	0	34	37	0	0
Sakhalin Island Taiga	1	36	4	4	4	4	4	4	4	4	4	5	4	4
Sarmatic Mixed Forests	1	3	3	10	72	91	117	42	166	20	3	139	104	93
Tundra	1	55	35	39	10	39	55	48	11	45	14	48	45	10
Sayan Montane Conifer Forests	2	350	115	187	112	245	171	131	201	188	67	181	127	115
Scandinavian And Russian Taiga	2	286	55	125	59	82	93	101	214	191	367	115	86	224
Forests	1	0	40	50	27	2	37	6	10	13	54	2	25	27
Scandinavian Montane Birch Forest And Grasslands	3	106	521	460	664	495	563	538	149	240	447	491	609	226
South Appenine Mixed Montane Forests	1	2	27	43	25	12	27	27	6	0	27	14	0	2
South Sakhalin-Kurile Mixed Forests	1	4	8	0	0	0	0	0	0	0	0	0	0	0
South Siberian Forest Steppe	1	37	82	84	119	29	93	138	9	0	50	97	0	0
Southern Anatolian Montane	1	70	0	0	0	0	0	0	0	0	0	0	0	0
Conifer And Deciduous Forests	1	70	0	0	0	0	0	0	0	0	0	0	0	0
Southwest Iberian Mediterranean														
Sclerophyllous And Mixed Forests	1	0	0	0	0	0	0	0	0	0	3	0	0	0
Sulaiman Range Alpine		•		10						_			10	_
Meadows	1	26	2	10	2	0	11	0	4	7	0	2	10	5
Taiheiyo Evergreen Forests	1	2	0	0	0	0	0	0	0	0	0	0	0	0
Taiheiyo Montane Deciduous Forests	1	16	0	5	4	1	0	0	0	0	0	0	0	0
Taimyr-Central Siberian Tundra	1	0	0	0	0	0	0	0	115	131	47	0	61	88
Tian Shan Foothill Arid Steppe	1	92	67	41	49	41	36	24	58	23	87	20	38	16
Tian Shan Montane Conifer Forests	1	52	19	24	38	55	26	40	55	8	26	42	8	0
Tian Shan Montane Steppe And Meadows	2	53	84	47	145	101	89	129	139	51	63	88	99	62
Trans-Baikal Bald Mountain	1	-	0	0	0	0	0	0	22	(0	2	0	0	0
Tundra	1	5	0	0	0	0	0	0	32	60	3	0	0	0
Tyrrhenian-Adriatic														
Sclerophyllous And Mixed	1	13	43	51	0	0	43	0	0	0	41	0	0	0
Forests														
Ural Montane Forests And Tundra	1	0	0	1	0	0	0	0	84	77	0	11	36	6
Ussuri Broadleaf And Mixed Forests	1	54	56	70	20	6	66	62	7	30	22	0	15	28

ECO_NAME	Terrestrial Ecoregion Clusters	C1_ 2020	C245_2040	C245_2060	C245_2080	C245_2100	C370_2040	C370_2060	C370_2080	C370_2100	C585_2040	C585_2060	C585_2080	C585_2100
West Siberian Taiga	3	294	195	448	398	391	195	451	360	109	207	547	91	12
Western European Broadleaf Forests	2	0	90	112	178	157	66	125	470	179	73	221	171	155
Western Himalayan Alpine Shrub And Meadows	1	7	3	2	4	4	3	2	18	0	6	4	0	0
Western Himalayan Broadleaf Forests	2	151	100	87	73	61	163	104	85	62	177	52	52	42
Western Himalayan Subalpine Conifer Forests	1	70	30	54	36	24	42	53	42	40	40	44	36	34
Western Siberian Hemiboreal Forests	1	4	4	0	19	101	7	85	0	0	0	183	0	0
Yamal-Gydan Tundra	1	21	9	31	12	15	35	60	139	116	37	51	143	105
Kazakh Steppe	1	40	132	61	0	0	64	0	0	0	35	0	0	0

Appendix A.8. Cluster Calculation (80–100%)

ECO_NAME	Terrestrial Ecoregions Clusters	C1_ 2020	C245_2040	C245_2060	C245_2080	C245_2100	C370_2040	C370_2060	C370_2080	C370_2100	C585_2040	C585_2060	C585_2080	C585_2100
Aegean And Western Turkey														
Sclerophyllous And Mixed	1	50	2	4	0	0	2	0	0	0	2	0	0	0
Forests														
Alps Conifer And Mixed Forests	4	512	585	663	647	769	548	852	822	899	638	959	1042	849
Altai Alpine Meadow And	2	174	56	52	115	85	72	57	71	129	96	114	80	41
Tundra	_													
Altai Montane Forest And Forest	1	105	41	54	24	48	38	75	71	65	60	48	46	62
Steppe	1	20	20	4	17	14	24	14	11	<i>,</i>	10	11	0	-
Altai Steppe And Semi-Desert	1	28	20	4	17	14	24	14	11	6	18	11	0	7
Anatolian Conifer And	1	100	0	0	4	8	0	8	2	0	0	4	6	0
Apponing Deciduous Montang														
Forests	1	9	51	45	44	3	57	26	0	0	59	7	0	0
Atlantic Mixed Forests	1	10	47	26	56	43	46	23	43	86	63	20	58	39
Azerbaijan Shrub Desert And			-		_					-	-		-	-
Steppe	1	0	0	5	5	0	2	0	0	0	0	0	0	0
Balkan Mixed Forests	1	53	102	67	53	31	107	34	21	2	101	21	5	0
Baltic Mixed Forests	1	13	26	25	13	33	15	15	38	39	27	13	47	16
Bering Tundra	3	136	343	306	281	465	292	656	130	64	497	514	214	82
Caledon Conifer Forests	1	14	0	10	5	6	1	9	0	15	0	0	5	8
Cantabrian Mixed Forests	1	0	24	25	8	18	1	8	25	55	70	106	113	39
Carpathian Montane Forests	1	0	1	35	52	92	6	84	178	180	7	89	106	79
Caspian Hyrcanian Mixed Forests	1	20	0	0	0	0	0	0	0	0	0	0	0	0

ECO_NAME	Terrestrial Ecoregions Clusters	C1_ 2020	C245_2040	C245_2060	C245_2080	C245_2100	C370_2040	C370_2060	C370_2080	C370_2100	C585_2040	C585_2060	C585_2080	C585_2100
Caucasus Mixed Forests	2	329	141	88	53	127	101	88	75	27	168	146	49	90
Celtic Broadleaf Forests	2	90	64	131	85	117	165	67	87	109	64	71	116	166
Central European Mixed Forests	2	15	40	0	15	155	19	378	113	23	40	232	93	10
Cherskii-Kolyma Mountain Tundra	1	0	12	60	64	101	7	67	65	21	82	152	126	99
Chukchi Peninsula Tundra	1	0	0	39	157	70	0	112	119	202	16	146	228	45
Corsican Montane Broadleaf And Mixed Forests	1	0	28	36	35	33	28	35	26	0	26	33	23	0
Crimean Submediterranean Forest Complex	1	0	36	9	6	9	7	5	0	0	23	6	0	0
Dinaric Mountains Mixed Forests	2	70	31	170	148	128	77	153	75	0	25	138	77	0
East European Forest Steppe	2	20	148	284	263	78	138	169	7	15	221	125	26	0
East Siberian Taiga	2	77	42	137	131	159	50	233	177	49	304	58	7	29
Eastern Anatolian Deciduous Forests	1	10	32	0	0	0	30	0	0	0	14	0	0	0
Eastern Anatolian Montane Steppe	1	117	38	9	12	7	29	15	2	0	26	18	4	9
Emin Valley Steppe	1	0	0	0	8	0	0	0	0	0	0	0	0	0
Euxine-Colchic Broadleaf Forests	1	19	79	59	76	58	72	73	43	0	71	98	5	0
Gissaro-Alai Open Woodlands	2	152	184	192	226	162	220	251	111	72	190	195	79	76
Himalayan Subtropical Pine Forests	1	22	8	5	8	0	0	1	0	0	0	0	0	0
Hokkaido Deciduous Forests	1	2	35	81	20	10	12	12	121	20	50	30	10	0
Hokkaido Montane Conifer Forests	1	20	15	54	4	12	7	4	91	0	40	23	0	0
Honshu Alpine Conifer Forests	1	12	12	4	16	0	0	0	0	0	16	0	0	0
Iberian Conifer Forests	1	0	19	0	0	0	0	0	0	0	0	0	0	0
Iberian Sclerophyllous And Semi-Deciduous Forests	1	49	0	0	0	0	0	0	0	0	0	0	0	0
Illyrian Deciduous Forests	1	45	0	0	0	0	6	0	0	0	18	0	0	0
Italian Sclerophyllous And Semi-Deciduous Forests	1	105	22	19	18	0	17	13	0	0	53	5	1	0
Junggar Basin Semi-Desert	1	14	0	0	0	0	9	5	4	0	11	5	0	0
Kamchatka Mountain Tundra And Forest Tundra	2	122	373	28	0	0	87	5	0	0	494	34	0	0
Kamchatka-Kurile Meadows And Sparse Forests	2	10	169	58	31	14	314	21	15	16	202	60	24	8
Kamchatka-Kurile Taiga	1	0	4	0	0	0	0	0	0	0	6	0	0	0
Karakoram-West Tibetan Plateau Alpine Steppe	1	16	1	122	56	105	32	98	94	87	19	50	65	80

ECO_NAME	Terrestrial Ecoregions Clusters	C1_ 2020	C245_2040	C245_2060	C245_2080	C245_2100	C370_2040	C370_2060	C370_2080	C370_2100	C585_2040	C585_2060	C585_2080	C585_2100
Kazakh Forest Steppe	2	112	80	90	70	24	173	75	16	9	132	21	16	1
Kazakh Upland	1	25	32	17	0	0	0	0	0	0	9	0	0	0
Kola Peninsula Tundra	1	13	15	19	12	0	0	0	0	0	0	0	0	0
Lake: Palearctic	1	7	0	0	0	0	0	1	0	0	0	0	0	0
Nihonkai Montane Deciduous	1	100	24	01	45	1	20	1	0	0	05	0	0	0
Forests	1	100	34	21	45	6	20	6	0	0	95	8	0	0
Northeast Siberian Taiga	2	14	175	146	64	101	39	92	33	0	373	102	115	56
Northeastern Spain And														
Southern France Mediterranean	1	24	2	43	4	8	2	10	6	4	17	13	2	4
Forests														
Northern Anatolian Conifer And	1	25	16	50	= /	50	41	= /	20	0	20		10	10
Deciduous Forests	1	35	46	50	56	52	41	56	39	8	30	55	10	12
Northwest Iberian Montane	1	(2)	(0	16	0	0	11	0	0	0	22	0	0	0
Forests	1	62	60	40	0	0	11	0	0	0	22	0	0	0
Northwest Russian-Novaya	1	0	(0	77	01	05	101	2	0	0	0	0	0	0
Zemlya Tundra	1	0	69	11	01	65	101	2	0	0	0	0	0	0
Northwestern Himalayan Alpine	2	214	112	174	00	74	279	172	110	122	227	00	102	110
Shrub And Meadows	Z	214	115	1/4	90	/4	278	173	119	133	227	90	105	110
Okhotsk-Manchurian Taiga	2	55	22	16	56	68	123	114	112	226	75	123	107	138
Pamir Alpine Desert And Tundra	2	93	137	238	252	226	160	272	199	225	150	251	149	174
Pannonian Mixed Forests	1	0	134	93	81	27	72	31	0	0	89	28	18	0
Paropamisus Xeric Woodlands	1	0	0	0	0	0	0	0	0	1	0	0	0	17
Pindus Mountains Mixed Forests	1	16	75	57	67	0	68	2	0	0	95	2	0	0
Po Basin Mixed Forests	1	5	2	0	0	0	2	0	0	0	0	0	0	0
Pontic Steppe	1	119	21	6	1	4	29	0	4	0	6	14	0	0
Pyrenees Conifer And Mixed	1	0	0	00	5	105	0	2	20	0	0	26	50	2
Forests	1	0	0	22	5	195	0	2	29	0	0	20	39	2
Rock And Ice: Palearctic	1	0	10	9	26	40	10	20	39	105	0	24	29	138
Rodope Montane Mixed Forests	1	10	31	40	47	18	32	31	0	0	35	32	0	0
Sakhalin Island Taiga	1	51	5	4	3	4	4	4	4	4	4	3	4	4
Sarmatic Mixed Forests	1	4	4	35	75	45	123	162	150	29	4	71	37	21
Sayan Alpine Meadows And	1	0	10	12	10	16	10	13	35	/11	14	21	16	31
Tundra	1	0	10	12	17	40	17	15	55	41	14	21	40	51
Sayan Montane Conifer Forests	2	251	82	97	137	134	65	100	163	155	133	143	96	59
Scandinavian And Russian Taiga	2	394	127	156	110	73	102	248	310	116	486	142	148	169
Scandinavian Coastal Conifer	1	0	47	43	4	22	26	33	2	5	35	22	0	0
Forests	1	0	7/	-13	Ŧ	~~	20	55	4	5	33	<u></u>	0	U
Scandinavian Montane Birch	3	84	494	518	538	496	449	420	282	255	324	400	478	242
Forest And Grasslands	0	01	1/1	510	556	170		120	202	200	524	400	10	272

ECO_NAME	Terrestrial Ecoregions Clusters	C1_ 2020	C245_2040	C245_2060	C245_2080	C245_2100	C370_2040	C370_2060	C370_2080	C370_2100	C585_2040	C585_2060	C585_2080	C585_2100
South Appenine Mixed Montane Forests	1	17	51	39	23	16	54	12	0	0	41	17	0	0
South Sakhalin-Kurile Mixed Forests	1	2	0	0	0	0	0	0	0	0	0	0	0	0
South Siberian Forest Steppe	1	24	14	17	72	82	57	82	0	0	54	52	0	0
Southern Anatolian Montane Conifer And Deciduous Forests	1	24	0	0	0	0	0	0	0	0	0	0	0	0
Sulaiman Range Alpine Meadows	1	5	0	0	0	0	0	11	0	0	0	0	5	0
Taiheiyo Evergreen Forests	1	0	0	0	0	0	0	0	0	0	2	0	0	0
Taiheiyo Montane Deciduous Forests	1	34	0	0	5	5	0	3	0	0	0	0	0	0
Taimyr-Central Siberian Tundra	1	0	0	0	0	0	0	0	88	142	0	0	61	48
Tian Shan Foothill Arid Steppe	1	0	18	34	18	30	23	3	27	34	24	18	0	3
Forests	1	10	58	30	12	0	11	11	0	0	30	20	0	0
Tian Shan Montane Steppe And Meadows	1	4	104	73	68	118	40	59	76	96	78	78	44	40
Trans-Baikal Bald Mountain Tundra	1	0	0	0	0	0	0	0	0	9	0	0	0	0
Tyrrhenian-Adriatic Sclerophyllous And Mixed Forests	1	27	43	10	0	0	41	0	0	0	43	0	0	0
Ural Montane Forests And Tundra	1	0	0	0	0	7	0	0	219	91	0	56	84	26
Ussuri Broadleaf And Mixed Forests	1	7	28	24	13	32	14	59	14	0	1	4	23	0
West Siberian Taiga	3	263	186	227	369	347	143	341	236	35	409	577	123	1
Western European Broadleaf Forests	2	30	113	203	146	234	147	226	254	129	38	258	288	158
Western Himalayan Alpine Shrub And Meadows	1	9	7	7	0	0	7	2	0	0	1	0	0	0
Western Himalayan Broadleaf Forests	2	169	167	85	113	56	139	63	70	70	132	66	31	28
Western Himalayan Subalpine Conifer Forests	1	69	26	32	40	26	39	39	41	41	33	36	40	29
Western Siberian Hemiboreal Forests	1	7	0	0	140	60	46	167	0	0	33	5	0	0
Yamal-Gydan Tundra	1	23	42	7	0	23	27	37	81	5	33	7	129	53
Kazakh Steppe	1	12	133	3	0	0	154	0	0	0	12	0	0	0

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