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Temporal variation of bird biodiversity and compositional complexity in a representative semi-Agricultural Natura 2000 area of conservation in Northern Greece

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ABSTRACT In this work we study the alteration in compositional diversity of bird abundances at the species level from 2012 to 2017 in one of the most important wetland Natura sites in Northern Greece and by using different biodiversity indices. Shannon Entropy was lower during 2012 (D_H = 1.509) albeit remained in similar levels from 2013 and afterwards. The highest values of Shannon Entropy were recorded in 2014 (D_H = 2.927) and 2016 (D_H = 2.888) suggesting that there is a higher diversity compared to the other observation years and especially 2012. The yearly trends of the Simpson dominance index and the Gini-Simpson Index had quite similar patterns. The Berger-Parker index, D_D, which represents the maximum proportion of any species estimated in the sample assemblage, had its highest values in 2012 (D_D = 0.58) and 2017 (D_D = 0.39) and its lowest in 2014 (D_D = 0.13) and 2016 (D_D = 0.15). A complete characterization of diversity was possible through the projection of Hill numbers and the Rényi entropy, parameterized by the order q in terms of an empirical curve. According to the Hills numbers pooled over the years, the mean species abundance (q = 0) was estimated at 31 species, the mean biodiversity (q = 1) was 13 species and the most dominant species (q = 2) were 8 species. The quantification of bird biodiversity in the particular research area patterns is a fundamental task to evaluate current management actions, improve conservation and design future management strategies.

KEY WORDS Birds; compositional complexity; biodiversity indices..

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INTRODUCTION

NATURA 2000 network is the main pillar of the European Union for the conservation of species biodiversity and the protection of the natural environment. The operation and configuration of the Natura 2000 network is based on two fundamental EU directives, the habitats directive (EU Habitats Directive: 92/43/EEC 1992)) and the Birds directive (EU Birds directive 2009/147/EC). According to theses directives the member states must assure that habitats are not degraded or disturbed, and monitor the condition of the protected species and habitats. Since the Natura network does not exclude human economic activities, such as farming, fishing, etc., it is quite important to have quantitative measures that can be used to evaluate the compatibility of human activities with protection of valuable species and habitats.

Quantitative biodiversity indicators include information that describe the biodiversity of species in different scales (Austin 1983). At a simplest level, the number of species in a community is a measure which referred as species richness or alpha diversity. However, species richness is a rather simple numerical count of the number of different types of species present since it does not takes into account species evenness which provides fundamental information on the uniformity of a species. Therefore, the use of more straightforward biodiversity (i.e., Shannon-Weaver), which combine the effects of richness and evenness, putting more or less weight to each case, provide a robust measure of species biodiversity (Maguran, 1988, 2004).

Because birds are very sensitive to habitat and environmental changes, they are therefore considered as one of the best indicators to monitor species biodiversity and provide vital information on the possible changes that are expected to occur in the future ecosystems (Niemi et al., 2004; Pan-European Common Bird Monitoring Scheme, 2006). In addition, because the extension of agricultural land and intensification of agriculture is widely recognized as a major cause of declining farmland bird populations, there is an ongoing interest in studying how bird biodiversity is affected during the past years by climate and human activities (Wilson, 1989; Malkolm et al., 2006; Sekercioglu et al., 2008; Guerrero et al., 2012).

The Thermaikos Gulf protected area is part of the European Natura 2000 ecological network of protected areas (Figs. 1, 2) and among the most important Natura cites in Greece offering major ecosystem services throughout many years (Karageorgis et al., 2006; Vareltizidou & Stinxer, 2009; Panagiotopoulou et al., 2012). The largest part of this protected area has been listed as a National Park, through Joint Ministerial Decision (JMD) 12966/2009 and includes the deltas and the estuaries of four rivers, the Lagoon of Kalochori and the Alykes Kitrous, the wetland of Nea Agathoupoli and the riverbed of Axios, reaching until the Elli dam (Axios Delta Management Authority, 2013). Although more than 290 bird species have been recorded in this area, of which some are globally threatened, current treats makes the management of the Thermaikos Gulf protected area a challenging goal (Kazantzidiz & Goutner, 2008; Vokou et al., 2018).

The aim of the current work was the study of some representative bird population in Northern Greece and how they change throughout the years using straightforward biodiversity indices that combine the effects of species richness and evenness. Moreover, since species abundance does not capture all information on species diversity, the scope was to provide for the first time a complete characterization of the compositional complexity of bird assemblages. Moreover, because measuring actual bird biodiversity is not an easy task the use of different summary statistics and related biodiversity indexes consist of a robust tool that accurately describe the trends in components of biodiversity under certain habitat conditions and can be further used as an important tool for decision makers (Purvis & Hector, 2000; Gregory, 2006).

Therefore, in order to quantify the differences on bird species community, the current study focus on the estimation of different biodiversity indices. Multiple statistical strategies and formulas are used to figure out which birds have declined or increased over time and to compare year to year variations in bird biodiversity. Proposing different statistical biodiversity indices, as well as measuring related changes in bird biodiversity, provide new information that is particular useful in evaluating conservation and habitat management actions. This is particularly important concerning that a big part of the protected area consist of agricultural cites. Additionally, positive or negative changes in the biodiversity indices over time may provide information on priority species and may be used to judge whether to modify or establishing new bird conservation plans (BCPs).

MATERIAL AND METHODS

Bird data and study area

For the current biodiversity study, we have used bird data of the Natura 2000 network that are freely accessible in the internet and published in the official website of the Thermaicos gulf protected areas management authority (Theramaikos gulf protected areas management authority, 2020). In particular, the data refer to monthly records of the number of bird

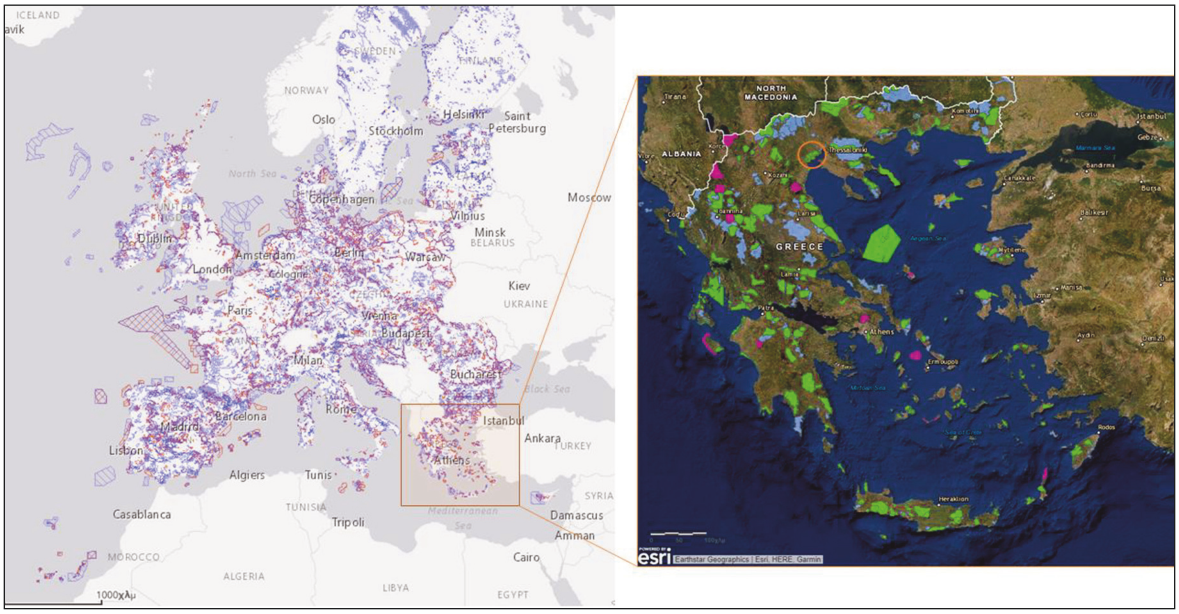

Figure 1. European Natura 2000 ecological network of protected areas (left) and the Natura 2000 ecological network in Greece (right) designed according to the Birds Directive (Spatial protection areas) and the Habitats Directive (Sites of Community Importance, and special areas of conservation). Green areas indicate spatial borders of sites, Pink areas: special protection areas of birds and blue areas zone of special protection of birds. The orange circle points the area were the research is performed (free maps provided by the EU Natura 2000 network public viewer and Esri earthstar geographics).

Figure 2. The Natura 2000 National Park of the Delta of Axios - Loudias - Aliakmon on the west coast of the Thermaic gulf in Northern Greece. The Green shadowed area represents the borders of the protected area including the delta created by three rivers Aliakmonas (red line), Loudias (pink line) and Axios (yellow line) (free map provided by Esri earthstar geographics).

species, from 2012 until 2017, from inside the spatial protection zone (GR1220010) of the Natura 2000 natural park which is located in the west coast of the Thermaic gulf in Northern Greece (Fig. 1). In addition, since there were instances in which some observations were absent (mostly due to technical reasons), the most complete and representative bird watching data sets from 2012 until 2017 were used.

The special geography and climatic conditions favor the development and evolution of a great diversity of bird populations. In particular, the location lies close to the coast and consist of a wetland complex which includes the Lagoon of Kalochori, the estuary of the Gallikos river, the delta of the Axios river, the estuary of the Loudias river, the delta of the Aliakmon river, the wetland of Nea Agathoupoli and the Alyki Citrus wetlands as well as closely related agricultural and semi urban areas (Fig. 2).

The climate of this area is classified as Csa Mediterranean climatic type (Köppen, 1923; Lochmann et al., 1993) with long, hot, and dry summers (the mean maximum temperature lies often in the range of 29.0 and 35.0 degrees of Celsius), relatively mild and rainy winters, and average annual air temperatures of approximately 15°C. To date, 299 bird species have been documented in the above area and represent close to 66% of all bird species observed in Greece (Theramaikos gulf protected areas management authority, 2020).

All data downloaded from the internet are intellectual property of the Thermaicos gulf protected areas management authority and have been used after permission for the particular research of the University of Alicante, Spain (license permission: Chalastra 19/3/2019, protocol number: 262).

Biodiversity indices

The biodiversity indexes are mathematical expressions which measure the species diversity in a community (Maguran 1988, 2004). The major advantage of biodiversity indices, compared to simply species richeness (i.e., number of species present), is the fact that they take in to account the relative abundance of different species and therefore, they provide important information on the species community structure. Since biodiversity indices enclose certain details and expression about the commonness and rarity of a species in a location and/or time of observation (Roth et al., 1994; Rosenzweig, 1995) numerous indices were taken into account.

In particular, for the present study the following diversity indices were estimated (Colwell, 2009):

Species richness

The species richness, D_S, refers to the total number of species, n_i, recorded in an ecological community, landscape or region (i.e., birds observed from a monitoring point). Thus:

(1) $D_S = \sum n_i$

Note that S does not take in to account abundances of the species but simply count the species found in a sample (Colwell, 2009).

Shannon Entropy

The Shannon diversity function, D_H, is a measure of the information necessary to specify an assemblage and probably the most common biodiversity measure. Shannon diversity is:

(2) $D_H = - \sum^{S}_{i=1} p_i \ln p_i$

Where S is the number of species and p_i is the relative abundance of species i (i.e., the number of species n_i divided by the total number of individuals N in that community, or: $p_i = n_i/N$). For an equal distribution, all species in the data set are equally common, the Shannon entropy has the value of the natural logarithm of Richness:

(3) $D_{H\max} = \ln (D_S)$

The physical-ecological interpretation of equations (2) and (3) is that the more unequal the proportional abundances of species, the smaller the Shannon entropy. For only one type in the data set, Shannon entropy equals zero. Therefore, high Shannon entropy stands for high diversity and low Shannon entropy for low diversity.

Shannon's equitability

The Shannon's equitability is simply the Shannon diversity index divided by the maximum diversity:

$E_H = D_H / D_{H\max}$

Simpson diversity and dominance

The Simpson's diversity index (Simson, 1949), *D*, is a simple mathematical measure that characterizes the species diversity in a community and is:

$D = -\sum^{S}_{i=1} p^2_i$

In addition, the reciprocal of Simson index is often used in the same context and referred as Simson dominance index:

(4) $D' = 1 / \sum^{S}_{i=1} p^2_i$

where S is the number of species and p_i is the relative abundance of species *i* (i.e., the number of species divided by the total number of individuals in that community).

(Gini) Simpson's dominance (evenness) index

The Simpson's dominance index, $\bar{D}$, is related to the usually Simpon's Diversity index, *D*, as follows:

(5) $\bar{D} = 1 - D$

$\bar{D}$ corresponds to true probability value and therefore this metric ranges from 0 (perfectly uneven) to 1 (perfectly even) (Guiasu & Guiasu, 2012). According to Hulbert (1971), the Simpson evenness stands for the probability of interspecific encounter between two specimens, which are picked randomly from a sample. Moreover, Simpson's evenness is mathematically closely related to rarefaction estimates of species richness.

Berger-Parker Index

The Berger-Parker index, (referred as species dominance in Berger and Parker 1970) is the maximum proportion of any species in a sample:

(6) $D_D = \max p_i$

If the community (sample) is dominated by the most common species and it is not even then The Berger-Parker index should be high.

Hill numbers and complete characterization of the species diversity

Hill numbers, *q*, or the effective number of species, are increasingly used to characterize the taxonomic, phylogenetic, or functional diversity, ^qD, of an assemblages (Chao et al., 2014; Chao & Jost, 2015). In the current study the first four Hill numbers are also estimated for comparative reasons, namely: $q = 0$ (species richness), $q = 1$ (the exponential of Shannon's entropy index), $q = 2$ (the inverse of Simspon's concertation index).

Hill numbers (Hill, 1973), consist of a class of diversity measures which integrates species richness and species abundances as follows:

$^qD_y = (\sum^{S}_{i=1} p^q_i)^{1/(1-q)}$, q#1

Where S is the number of species in an assemblage, p_i is the relative abundance of the *i*th species and q is a parameters which determines the sensitivity of the measure to relative frequencies.
For q=0, then ^0D is simply the species richness.
For q=1, $^1D = \lim (n\rightarrow 1)\ ^qD_y = \exp(-\sum^{S}_{i=1} pi\ lnpi)$

Which is the exponential of the Shannon index which weights the species in proportion to the frequency.

For q=2, $^2D = \sum^{S}_{i=1} pi$

Which is the Simson's diversity index.

The complete characterization of the species assemblages is estimated also for q = 3, q = 4 and for q = ∞ and further conveyed by a diversity plot generated for each observation year.

Rényi entropy and generalized biodiversity dimensions

The Rényi entropy, $H_a(p)$ is a generalization of Shannon's entropy. $H_q(p)$ of order $q \in [0, \infty]$ is estimated as:

$H_q(p) = 1/1\text{-}a \ln \sum^{S}_{i=1} p^q i$

where *q* is a parameter that modulates the index's sensitivity to species abundances. Shannon entropy is the limiting instance of Rényi entropy as q→1 (Daly et al., 2018).

For the given bird abundance data set from 2012 throughout 2017 these complexity measures are plotted as a continuous empirical function of *q* to capture the changes of the single bird assemblage over the different time periods.

RESULTS

Bird species records in the Theramaikos gulf Natura 2000 protected area

The Thermaikos gulf protected area has a rich diversity of birds. According to the review on the available data of the spatial protection zone (GR1220010), which are published by the Natura 2000 management body, a total of 71 species were recorded from 2012 until 2017. These include the species shown in Table 1 (Theramaikos gulf protected areas management authority, 2020). Among them the most predominant species were: *Ergetta garzetta* (470 individuals), *Himantopus himantopus* (592 individuals), *Philomachus pugnax* (353 individuals), *Tringa sp* (493 individuals) (Fig. 3).

Yearly trends of bird community's biodiversity indices

Figure 4 depicts the annual changes of the bird biodiversity indices which were calculated using available data from 2012 until 2017. Shannon Entropy was

Accipiter nisus (Accipitridae, bird of prey)	*Actitis hypoleucos* (Scolopacidae)	*Anas clypeata* (Anatidae, Water bird)
Anas crecca (Anatidae, water bird)	*Anas querquedula* (Anatidae, migratory water bird)	*Anas penelope* (Anatidae, Water bird)
Anas platyrhynchos (Anatidae, water bird)	*Anthus campestris* (Motacillidae, migratory)	*Ardea cinerea* (Ardeidae, Predatory wading bird)
Ardea purpurea (Ardeidae, water bird), *Botaurus stellaris* (Ardeidae, water bird), *Burhinus oedicnemus* (Burhinidae water bird)	*Ardeola ralloides* (Ardeidae, migratory bird), *Buteo buteo* (Accipitridae, bird of prey), *Calidris alpine* (Scolopacidae, migratory bird)	*Athene noctua* (Strigidae bird of prey) *Buteo rufinus* (Accipitridae bird of prey), *Calidris ferruginea* (Scolopacidae, migratory wading bird)
Calidris minuta (Scolopacidae, migratory)	*Calidris* sp. (Scolopacidae, migratory bird)	*Casmerodius albus* (Ardeidae, migratory wading bird)
Charadrius alexandrines (Charadriidae, water bird)	*Charadrius dubius* (Charadriidae, migratory bird)	*Chlidonias leucopterus* (Laridae, migratory)
Chroicoceplalus gene (Laridae, migratory bird)	*Ciconia ciconia* (Ciconiidae, migratory bird)	*Ciconia nigra* (Ciconiidae)
Circaetus gallicus (Accipitridae, bird of prey)	*Circus aeruginosus* (Accipitridae, bird of prey)	*Circus cyaneus* (Accipitridae, bird of prey)
Circus pygargus (Accipitridae, migratory bird of prey)	*Coracias garrulous* (Coraciidae)	*Cygnus olor* (Anatidae, swan)
Emberiza melanocephala (Emberizidae, migratory)	*Egretta garzetta* (Ardeidae, migratory bird)	*Ergetta alba* (Ardeidae migratory wading bird)
Falco tinnunculus (Falconidae, bird of prey)	*Fulica atra* (Rallidae, vagrant)	*Gallinula chloropus* (Rallidae, migratory water bird)
Gallinago gallinago (Scolopacidae)	*Gelochelidon nilotica* (Laridae, migratory	*Glareola pratincola* (Glareolidae, migratory)
Himantopus himantopus (Recurvirostridae, water bird)	*Hydrocoloeus minutus* (Laridae, vagrant)	*Larus genei* (Laridae, vagrant)
Larus melanocephalus (Laridae, water bird)	*Larus michahellis* (Laridae, migrant)	*Larus ridibundus* (Laridae, migratory)
Melanocorypha calandra (Alaudidae)	*Motacilla alba* (Motacillidae, migratory)	*Motacilla flava* (Motacillidae, migratory)
Nycticorax nycticorax (Ardeidae, migratory)	*Numenius arquata* (Scolopacidae, migratory)	*Phalacrocorax carbo* (Phalacrocoracidae, migratory wading bird)
Phalacrocorax pygmeus (Phalacrocoracidae, partially migratory)	*Philomachus pugnax* (Scolopacidae, migratory)	*Phoenicopterus roseus* (Phoenicopteridae, migratory wading bird)
Phoenicopterus ruber (Phoenicopteridae, wading bird)	*Platalea leucorodia* (Threskiornithidae, migratory)	*Plegadis falcinellus* (Threskiornithidae, migratory wading bird)
Sternula albifrons (Laridae, migratory seabird)	*Sterna nilocita* (Gelochelidon, migratory)	*Tachybaptus ruficollis* (Threskiornithidae, migratory wading bird)
Tadorna tadorna (Anatidae)	*Tringa* sp. (Scolopacidae)	*Tringa glareola* (Scolopacidae, migratory)
Tringa nebularia (Scolopacidae, migratory, wading bird)	*Tringa tetanus* (Scolopacidae)	*Upupa epops* (Upupidae)
Vanellus spinosus (Charadriidae, wading bird)	*Vanellus vanellus* (Charadriidae, migratory)	

Table 1. Bird species (family, and basic ecological characteristics) registered by the management authority in the spatial protection zone (GR1220010) of the Natura 2000 National Park of the Delta of Axios - Loudias - Aliakmon in Northern Greece from 2012 until 2017.

lower during 2012 (D_H = 1.509) albeit remained in similar levels from 2013 and afterwards. The highest values of Shannon Entropy were recorded in 2014 (D_H = 2.927) and 2016 (D_H = 2.888) suggesting that there is a higher diversity compared to the other observation years and especially 2012.

Shannon's equitability index, E_H, showed similar patterns and was respectively higher in 2014 (E_H = 0.85) and 2016 (E_H = 0.79) compared to all other years of observation and especially 2012 which had its lowest values (E_H = 0.46). This was expected considering that E_H is the product of the Shannon diversity index divided by the maximum diversity and normalizes D_H to a value between 0 and 1 (Fig. 3). The higher values of E_H calculated in 2014 and 2016, respectively, represent virtually a very high equitability of species which is quite close to complete species evenness.

The yearly trends in Simpson dominance index, D', in respect to year are shown in figure 5. Because D' measures the probability that two individuals randomly selected from a sample belong to the same species, values close to 0 represent infinite diversity and values close to 1, no diversity at all. The lowest values of this index were calculated in 2014 (D' = 0.06) and in 2016 (D' = 0.08), whilst the highest in 2012 (D' = 0.39) and 2017 (D' = 0.2).

Moreover, the Gini-Simpson Index, $\bar{D}$, is following similar annual patterns with the affront mentioned indices (Fig. 5). The value of this index ranges between 0 (all species are equally present) and 1 (one species dominates the community completely). This is because the index gives more weight to the species which is more abundant in the sample and penalizes the addition of rare species because they cause only small changes in its value. In particular, the Gini-Simpson Index $\bar{D}$ has had its highest value in 2014 ($\bar{D}$ = 0.93) and 2016 ($\bar{D}$ = 0.92) and the lowest in 2012 ($\bar{D}$ = 0.61) and 2017($\bar{D}$ = 0.8). Therefore, we conclude that during 2014 and 2017 some bird species dominate more compared to the other observation years.

Finally, the Berger-Parker index, D_D, which represents the maximum proportion of any species estimated in the sample assemblage, had its highest values in 2012 (D_D = 0.58) and 2017 (D_D = 0.39) and its lowest in 2014 (D_D = 0.13) and 2016 (D_D = 0.15) (Fig. 5). From a practical standpoint and according to Hubbell's neutral theory (Hubbell, 2001), alterations in the D_D values represent different colonization rates shift distributions towards even patterns which are represented by low D_D values (Caruso et al., 2007). Therefore, successful colonizing bird species have probably dominated more the assemblage in 2017 and 2014 and thus determined the increase in the Berger-Parker index.

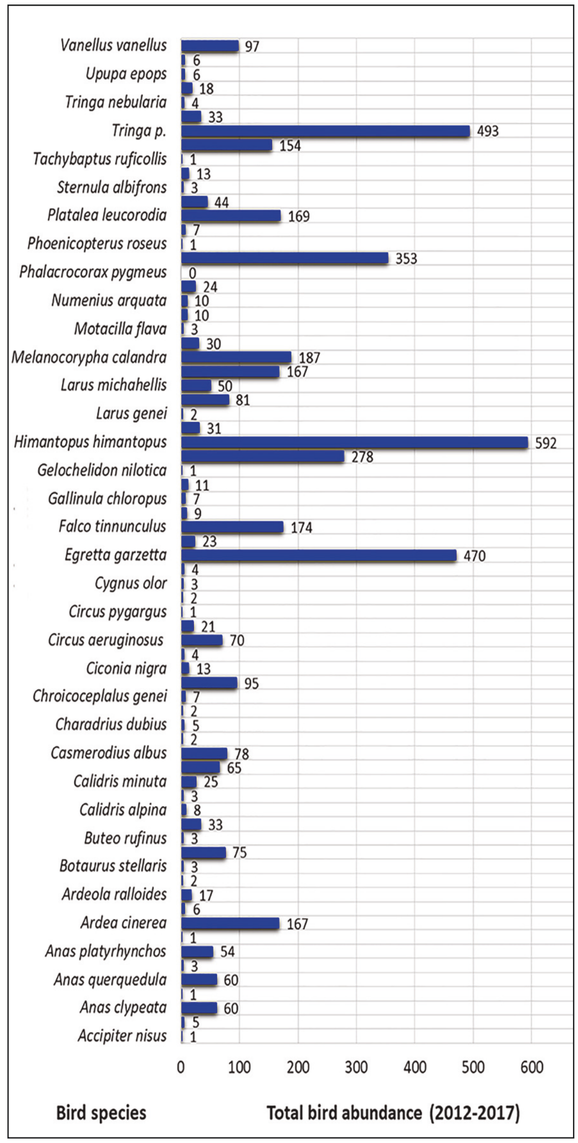

Figure 3. Total bird species abundance recorded inside the spatial protection zone (GR1220010) of the Natura 2000 natural park on the west coast of the Thermaic gulf in Northern Greece from 2012 until 2017.

Hill numbers biodiversity profiles

A complete characterization of diversity of the yearly bird assemblages in the Theramaikos gulf Natura 2000 protected area is shown in figure 6 which shows the empirical values of the Hill numbers and the Rényi entropy parameterized by the order q in terms of an empirical curve (McGuiness, 1984).

In particular, the diversity and entropy profiles in figure 7 are plotted for all values from $q = 0$ through infinity, although are not shown from $q = 4$ and beyond, because they do not change essentially and thus do not contain much information on the compositional complexity of the bird assemblages.

The first three numbers coincides with three diversity indices, namely the true diversity of all species ($q = 0$; species richness), the diversity of typical (common) community species ($q = 1$; exponential of the Shannon-Wiener diversity index) and the diversity of the dominant species ($q = 2$; the reciprocal of Simson's diversity). The bars thus represent species and, as the number increases, less weight is given in rare species units of the number decreases and are helpful to assess and compare the yearly time effects on species dominance. In general the profiles of the yearly assemblages do not cross unambiguously between them but for 2015 and 2016, suggesting that these two year were more diverse compared to the other. In most cases the bird assemblages showed similar diversity patterns in respect to the first Hill numbers although the values were different.

The species richness (q = 0) were higher in 2016 ($D_S = 38$) and 2015 ($D_S = 37$), followed by 2014 ($D_S = 31$) and by 2013 and 2017 which have the same levels ($D_S = 29$). The lowest species richness was estimated in 2012 ($D_S = 26$). Moreover, the bird biodiversity (Hill number $q = 1$) were higher for 2014 (${}^1D_y = 18.662$) and 2016 (${}^1D_y = 17.953$) compared to 2013, 2015 and 2017 which were lower ($9.465 < {}^1D_y < 14.429$). The lowest biodiversity was estimated in 2012 (${}^1D_y = 4.521$).

Moreover, the effective number of the dominant bird species (Hill number $q = 2$) were higher in 2014 (${}^2D_y = 14.399$) and 2016 (${}^2D_y = 12.505$) compared to 2013 (${}^2D_y = 10.213$) and 2015 (${}^2D_y = 8.629$). The lowest values were estimated in 2017 (${}^2D_y = 4.993$) and 2012 (${}^2D_y = 2.563$). The above values have biological sense since realistically represent the effective number of bird species (i.e., with the same abundance) in respect to each observation year that theoretically can coexist with the maximum evenness. The Hill numbers q>3 have shown similar patterns with the previous parameters although taking slight lower values, although during 2012 the Hill's curve is more uneven (steeper decline) compared to all other years. Figure 5, shows the pooled over the years values of the Hill number biodiversity indices. The mean species abundance (q = 0) was 31 species, the mean biodiversity (q = 1) was 13 species and the most dominant species (q = 2) were 8 species.

Rényi entropy biodiversity profiles

The Rényi entropy profiles generally follow the same patterns as the Hill numbers in respect to each observation year (Fig. 8). Moreover, in all cases the

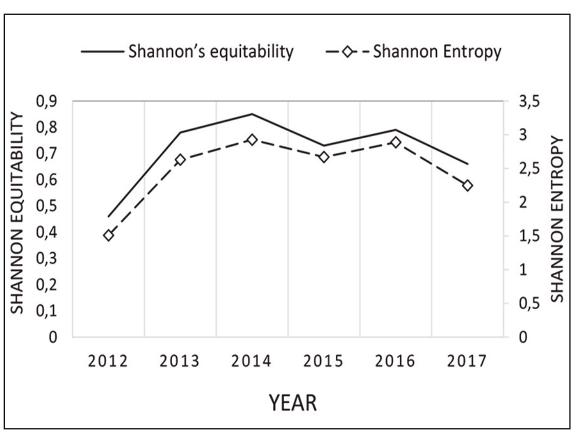

Figure 4. Yearly trends and relative analogies of the Shannon's entropy and related Shannon's equitability index of bird biodiversity of a representative site of the Natura 2000 Thermaikos gulf protected area in Northern Greece.

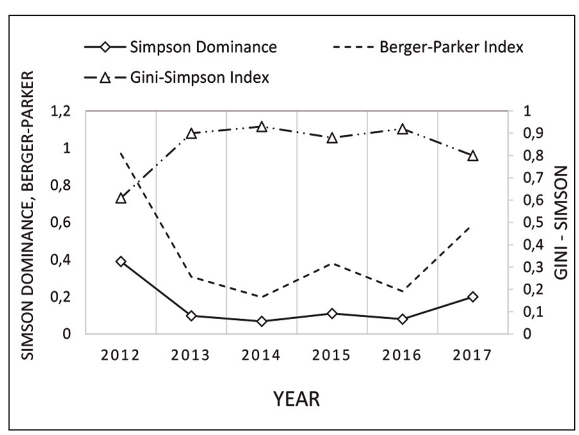

Figure 5. Yearly trends of the Simpson dominance, Gini-Simpson and Berger-Parker indices of bird biodiversity of a representative site of the Natura 2000 Thermaikos gulf protected area in Northern Greece.

Rényi entropy profiles showed analogous diversity patterns as for the first Hill numbers. Higher values were estimated for 2014 and 2015 compared to all other years. This suggest that these two years were more diverse compared to the other. Finally, a slight crossing appears in 2014 and 2016 with 2013 and 2015 when moving from the parameter q = 0 towards q = 1.

DISCUSSION

Birds are relatively easy to see and count and, due to their sensitivity in habitat conditions, birds can be used as reliable indicators of species biodiversity on practical and scientific grounds. Birds, particularly, are diverse, are high in the food chain, which makes them sensitive to changes at lower food change levels (Thomas et al., 2004), they are also sensitive to landscape modification as well as to the presence of persistent pollutants (Barker & Tingey, 1992; Backhaus et al., 2012). As a result, the quantification of yearly changes in the complexity of bird biodiversity provides important information which potentially can be further used to identify any driving forces behinds their temporal alterations (Crick, 2004; Visser et al., 2006).

Nevertheless, one disadvantage of using birds to estimate biodiversity, in general, as well as in the particular Natura site of interest, is that they do not often reflect of all other taxa in their domain (Gregory, 2006). Moreover, in some cases there are bird species in which it is realy hard to link their population abundances to specific drivers on the ground, since some species may counter positively to ground change, while other negatively. For example the excess of nutrients due to eutrophication may be detrimental in the round of a wetland for some species, but beneficial for others (i.e., wildfowls *Anas platyrhynchos*).

In this work we estimate and present for the first time the compositional diversity of bird abundances at the species level from 2012 to 2017 in one of the most important wetland Natura site in Northern Greece using several biodiversity indices. More than 50 bird species have been listed in total with a combination of water birds, endemic as well as migratory species. The highest values of most biodiversity indices were recorded in 2014 and 2016 suggesting that there is a higher compositional diversity compared to all other years of observation.

The bird biodiversity has been known to play an important role as biodiversity indicator in the well-being and health of ecosystems (Tucker & Evans, 1997). Therefore, there have been important endeavors to describe bird compositional complexity and its stability contributing to the evaluation of the sustainability of specific habitats and ecosystems.

In this work we have addressed the estimation of temporal changes of bird assemblages by means of a series different biodiversity measures, to aid in better understanding of the functioning and sustainability of this important Natura 2000 protected area in Northern Greece.

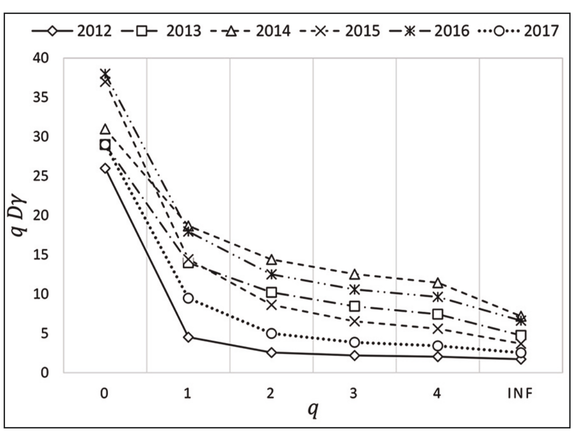

Figure 6. Characterization of the species diversity of an assemblage with Hill numbers that report the diversity of all species (q=0), the diversity of a "typical" species (q=1), and that of dominant species (q=2) as well as following dimensions.

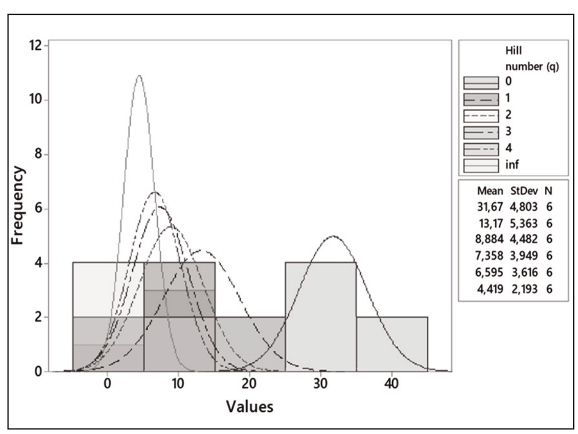

Figure 7. Pooled distribution patterns, first and second moments of the Hill number in estimating the mean bird biodiversity of a representative site of the Natura 2000 Thermaikos gulf protected area in Northern Greece.

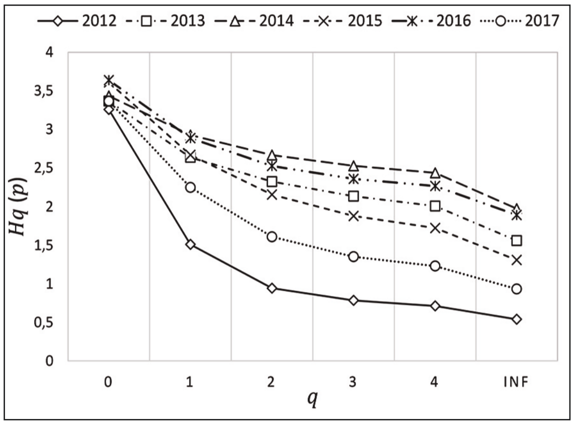

Figure 8. Complete characterization of the species diversity of an assemblage using Rényi entropy. The profile represents the diversity of all species (q=0), the diversity of a ''typical'' species (q=1), and that of dominant species (q=2) as well as following dimensions (details in text).

Because the concept of biodiversity is rather straightforward considering the partitioning diversity into different components (i.e., richness, evenness, relative abundance etc) (Wagner et al., 2018), we have decided to estimate and compare a series of different biodiversity indices to provide an holistic approach to characterize the particular composition of bird assemblages. Furthermore, we have decided to calculate and compare the time related biodiversity curves for each index to detect alterations and analogies between the different measures. This provide a robust measure of bird compositional biodiversity as well as information upon the changes throughout time.

Although both Shannon's diversity as well as Simpson's index are both estimators of biodiversity, the first put more weight on species richness, while the second, on species evenness (Kim et al., 2017). To date, species richness is the number of different species present in a certain niche which does not take into account the number of each species present in contrast to evenness, which includes information on the uniformity of the population size of each of the species present. Therefore, a major advantage over simple diversity measures, such as richness and evenness, is the fact that they provide more inference about the structural composition of the bird populations. Moreover, although in Shannon's diversity as well as Simpson's index the sample size is generally negligible for both of them, it is often difficult to compare communities that differ greatly in richness based solely on Shannon's diversity.

In the current study the Shannon Entropy had the highest values in 2014 ($D_H = 2.927$) in 2014 and in 2016 ($D_H = 2.888$), suggesting that there is a higher diversity compared to all other observation years. These high values may be related to a higher number of species and/or a distribution which is more even compared to other cases (Magurran, 2004). In general, typical values of Shannon Entropy are generally between 1.5 and 3.5 in most ecological studies, and the index is rarely greater than 4. However, because these values are related to the particular study region, it is difficult to be compared to other regions *per se*. On the other hand, because the Simpson index varies for 0 to 1, it can be probably used to compare more easily relative analogies to species bio diversities of other regions.

Moreover, the empirical curve profiles of the Hill's numbers, as well as the Rényi entropy, provide a quantification in the change in the shapes of the curves over time and the ability to compare their different patterns in relation to the different observation years. In 2012 and 2017, for instance, the shapes of the diversity curves differ considerable compared to all other years and which explains visually the discrepancies in comparing the other diversity indices. In other words, although the other biodiversity indices used evaluated the temporal changes in bird biodiversity, Hill's and Rényi complexity measures may provide different answers related to weight given to rare species (Wagner et al., 2018). Thus, the biodiversity curve profiles have the advantage of providing information about the change in the evenness of the bird assemblages over time in a single model.

However, it is still important to generalize the information from the biodiversity indicators in order to establish a link to the driving causes which explain any ecological variation in bird abundance from year to year as well as from location to location. For instance, when an ecosystem degrade, a few generalist species, that can thrive in wide variety in habitat modified by human, take over a large number of specialist species which are decently strongly by absolute precise habitat conditions. As a result, small population of native species become extinct and a few generalist species dominate. This process of such a temporal change is known as *biotic homogenization* (Thomas et al., 2004). Therefore, very often neither the rarest nor the commonest species *per se* are reliable indicators of biodiversity. Additionally, alterations of abiotic factors such as changing environmental temperatures, alterations in rainfall regime such as the amount of precipitation (rain, snow, etc.), the relative humidity of the atmosphere, as well as the increasingly frequent extreme weather events are characteristic elements of climate change and can possible affect species phenology, reproduction and biodiversity (Crick, 2004; Visser et al., 2006; Cormont et al., 2011; McMahon et al., 2011; Auer & Martin, 2013).

To conclude, based on the results there were alterations in bird assemblages throughout the observation years and especially during 2012 and 2017. Additionally, because the biodiversity indexes used in this study are representative and sensitive to environmental change they provide a capable quantitative measurement of the species occurred in the particular location of interest and their stability throughout time. Therefore, more work has been planned to answer the question of whether annual changes in the composition bird biodiversity are related to exogenous factors such as climate and/or any human activities. Yet, this study has shown that use of diversity indexes are robust estimators of biodiversity since they give as biodiversity by proxy and save us time and reduce sampling efforts since it is virtual impossible to survey everything. Information from this work should facilitate evidence-based strategies for the preservation and sustainable management of the Thermaicos semi-Agricultural Natura 2000 area of conservation in Northern Greece.

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