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ORIGINAL ARTICLE

Mediterranean wetland conservation in the context of climate and land cover change

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Abstract

Wetlands are known to support diverse and unique species assemblages. Globally, but particularly in the Mediterranean basin, they are threatened by climate change and natural habitat loss. Despite an alarming decline of wetlands over the last century, standardised and systematic site assessments at large scale do not exist. Here, we perform an integrated assessment of Mediterranean wetlands by evaluating the combination of wetland protection and anthropogenic pressures, namely climate and land cover change, and the subsequent impact on wintering waterbirds. We used a multivariate partial triadic analysis to quantify climate and land cover change for each site between 1990 and 2005. We found that wetland sites in the southeast of the Mediterranean basin combined low or no protection cover with the highest increases in temperature and losses in natural habitats. Despite these findings, these sites also lack observation data on biodiversity, which may underestimate the resulting impacts. However, there are examples where active conservation measurements contributed positively to slow down wetlands' reduction. Biodiversity data coverage needs to be ensured, regularly updated, and extended across sites regardless of their protection level, to allow for the assessment of biodiversity trends. This should be further extended to include current investments in remote sensing approaches.

Keywords Waterbirds · Partial triadic analysis · Biodiversity change · Indicators · Protected areas

Introduction

Mediterranean wetlands are of major concern, experiencing an estimated 50% loss over the last century (Perennou et al. 2012; Geijzendorffer et al. 2018). At the same time, the Mediterranean basin is recognised as both a biodiversity and a climate change hotspot (Giorgi 2006; Myers et al. 2000). Although currently still hosting a wide variety of endangered species, the basin is expected to experience dramatic changes in the coming decades (Klausmeyer and Shaw 2009; García-Ruiz et al. 2011; Guiot and Cramer 2016). Climate change has already increased mean temperatures by 1.4 °C in the region since the preindustrial period (Cramer et al. 2018) and has also led to a rise in the frequency of severe drought events (Mariotti et al. 2008). In addition, the increase in land cover change and land-use intensity over the last 50 years is deteriorating wetlands (Cuttelod et al. 2009), with future projections predicting a rise in human population density and additional loss of natural areas (Bradshaw and Brook 2014). These dynamics have severe implications for wetlands, among which a significant decline in avian species as well as consequences for human

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well-being at both local and regional scales (Schröter et al. 2005; Galewski et al. 2011; Amano et al. 2018).

In the last decades, policymakers have reacted by implementing policy instruments (e.g. national conservation strategies, European Directives, Bern or Ramsar conventions) and increasing the extent of protected areas at national and international level. The evaluation of these instruments at the national and, particularly, international level relies on large-scale assessments (Gardner et al. 2015). Regular reporting on the state and trends of ecosystems, biodiversity, and their drivers not only improves the understanding of the underlying processes but also facilitates informed decision-making (Kark et al. 2009).

In the Mediterranean, like elsewhere in the world, data are mostly scattered and without regional coherence across borders (Kark et al. 2009). Although Mediterranean wetland assessments are done at a regional and national scale (Geijzendorffer et al. 2018), site-based approaches (e.g. per protected areas) for reporting wetland states are lacking. The recent development of essential variables (defined as variables that permit quantification of the rate and direction of change over time and across space; Pereira et al. 2013; Bojinski et al. 2014) allows for large-scale assessments in different ecological contexts. These include informing about the ocean biodiversity and ecosystem changes (Miloslavich et al. 2018) analysing policy objectives (Geijzendorffer et al. 2016), as well as reporting and developing species monitoring programmes (Schmeller et al. 2015). Essential variables can also be used to identify large-scale indicators available at high resolution enabling for site-specific assessment. Their identification can allow the harmonisation of monitoring efforts across sites, coordination facilitation, and data collection prioritisation, which in turn benefits decision-making (Turak et al. 2017). Following an essential variable (EV) framework, Turak et al. (2017) identified 22 priority activities for freshwater biodiversity conservation to be tackled by 2020 to allow its global mapping. In our study, we put those recommendations into practice by testing different variables for wetland monitoring. We used harmonised and standardised site-based data (species, climatic, and habitat-extent) at high spatial resolution across the Mediterranean.

Wetland biodiversity is highly sensitive to climate and land-use changes that can affect species assemblage including birds with population declines and community changes of avian species or families (Robledano et al. 2010; Amano et al. 2018). As waterbirds are highly dependent on freshwater ecosystems and present the highest data quality available in space and time, they are usually used as wetlands' indicator (Lehikoinen et al. 2016; Amano et al. 2018). They are sensitive to changes in wetland characteristics, such as the water level, water quality, and disturbances (Tamisier and Grillas 1994). Even though the overall waterbird population trend within the Mediterranean basin has been assessed as positive, this trend was mainly driven by the bird population in the West as significant population depletion was accounted in the East (Galewski et al. 2011). This would have resulted from a lack of wetland and waterbird conservation effectiveness against anthropogenic threats in the Eastern Mediterranean, including climate and habitat changes (Gaget et al. 2018; Gaget et al. 2020). Increase in both drought frequency and average temperature (Mariotti et al. 2015) is expected to affect the wetland characteristics, and therefore, reduces their suitability for waterbirds (Tamisier and Grillas 1994).

Here, we assessed the effects of climate and land cover change on natural wetland habitats between 1990 and 2005 in the Mediterranean basin and sequentially on waterbird species diversity. From the species abundance on each wetland site, we calculated the average species diversity (Simpson diversity) and temporal species turnover (Sorensen beta diversity) to characterise population change between and within wetlands. Through the use of environmental variables related to essential variables for freshwater biodiversity (Turak et al. 2017), we (1) identified the sites that were most affected by climate or land cover change, (2) evaluated the protection coverage of the reported Mediterranean wetlands and how this related to the preservation of natural areas, (3) assessed a potential effect of those climate and land cover changes on waterbirds taking into account the protection coverage, and (4) tested a baseline approach for regional wetland monitoring assessments, reflecting on its values and shortcoming as well as future perspectives.

Methods

Wetland sites

We considered 236 wetland sites located within a region defined by the limits of coastal watersheds that drain into the Mediterranean Sea. The wetland site compilation involved the collection of data through different channels, such as the Mediterranean Wetland Outlook (MWO) that identified wetland sites from the north of the Mediterranean Sea, mainly based on national, European, and global databases on protected areas, as well as the national Ramsar authorities that referenced the Maghreb and the Near East sites (Table S7). We classified each wetland site according to the protection coverage, relative to the surface area of a site considered under a protection programme or convention such as Natura 2000, National Park, or Ramsar (i.e. 'high protection coverage' [> 50% of the total surface area of a site], 'low protection coverage' [≤ 50%], and 'no protection coverage' [0%]).

Data processing

We identified 15 variables that describe climatic, land cover, and bird species patterns closely related to wetland ecosystem structure. Those variables were partitioned into four EV classes (i.e. species abundance, ecosystem structure, temperature, precipitation (Pettorelli et al. 2016; Gill et al. 2017), Table S6) and used to produce indicators (e.g. percentage of wetland change). The variables were selected according to their availability and their accordance with common criteria: (i) cover the wetland sites uniformly, (ii) overlap in time—all variables were representative of two periods (1990 and 2005), and (iii) have high spatial resolution capable of describing local processes.

To capture the climatic part of wetlands' hydrological cycle, we selected climate and precipitation variables which encompass both average and extreme climatic conditions (e.g. leading to aridity). The climate variables were downloaded from CHELSA (Karger et al. 2017) such as monthly mean, maximum, and minimum temperature (°C) from which four variables were derived: (1) annual temperature mean (Tmean), (2) temperature seasonality (Tseas), (3) maximum temperature of the warmest month (Tmax), (4) minimum temperature of the coldest month (Tmin), and monthly precipitation (mm) data from which another four variables were processed: (1) annual precipitation (Pmean), (2) precipitation of the wettest month (Pwet), (3) precipitation of the driest month (Pdry), and (4) precipitation seasonality (Pseas). We computed yearly climatic variables using monthly data from 1986 to 1995 as a representation of 1990's climate, and from 2001 to 2010 to represent 2005's climate. We also transformed each climatic and land cover variable to produce indicators that account for changes. Concerning the climate variables, we performed a simple subtraction of their values at 2005 and 1990 such as variable diff = data2005 − data1990. We then obtained the difference in mean temperature (Tmean diff) and precipitation (Pmean diff), in temperature and precipitation seasonality (Tseas diff and Pseas diff), in maximum and minimum temperature of the hottest and coldest month (Tmax diff and Tmin diff), and in precipitation of the driest and wettest month (Pdry diff and Pwet diff).

In this study, we interpreted the variable 'habitat extent' as the surface area of six different land cover types within each wetland site: natural wetlands, artificial wetlands, urban areas, agricultural lands, natural wetlands, and sea (Land Use Land Cover (LULC) data, as defined by the Ramsar Convention, Table S1). We then transformed the initial km^2 unit of the land cover categories in percentage of cover per site (further used for the partial triadic analysis), and in percentage of change (PoC) per site via the following equation: variable PoC = (data2005 − data1990) / data1990. We considered the percentage of change of natural wetlands representative of the wetland state.

For the bird species data (wintering waterbirds only), two variables were produced for each site: Simpson diversity (alpha diversity) and Sorensen beta diversity. Both fit the population abundance EBV (Kissling et al. 2018). The population abundance was obtained from regular surveys occurring between 1991 and 2010. We represented the 1990 period by averaging the data from 1991 to 1995, and the 2005 period by averaging from 2006 to 2010. Each period (represented from 1990 and 2005) has a slightly different number of sites surveyed (130 and 178 respectively). Therefore, we used only the sites where both dates were sampled resulting in 111 sites. In this study, we presented the results from beta-Sorensen to measure the change in community species composition (beta diversity) and Simpson diversity to measure the change in populations (alpha diversity) to explain the species response to changes. We assumed both climate and land cover changes induce a species turnover by favouring the incoming of new species, and so increase beta diversity. By evaluating the trend in alpha diversity, we investigated if the change in beta diversity is related to an increase or a decrease in waterbird populations.

The wetland sites considered as 'protected' presented the following labels: Biotope Protection Order, Forest Reserve, Hunting Reserve, Land acquired by a regional conservatory of natural areas, land acquired by Natural Seaside and Lakeside Conservatory, Marine Protected Areas, Natura 2000, National Park, Nature Monument, Nature Park, Nature Reserve, protected area of Mediterranean Importance, Protected Landscape, Ramsar, Regional Park, Special Reserve, Waterfowl Hunting Bloc, Wildlife Refuge, World Heritage Site (Table S7). International labels like Important Birds Areas (IBA) that are not part of a convention and do not impose any legal constraint were not considered as a form of protection per se if no any other kind of protection overlapped. As labels often overlapped within a site without any clear management objective defined, we considered the total percentage of protection cover per site to implement a protection grade. We considered the percentage of protection covered per site above and below 50% and without protection as three protection levels: highly protected, low protection level, and not protected. The protected areas were designated from 1934 to 2016. Not all protected areas had information about their year of designation (n = 103, 44% of sites).

For LULC-derived variables, we used data from 236 wetland sites monitored in 1990 and 2005 at 30 m of spatial resolution and with a minimum mapping unit (MMU) = 1 ha (see the 'Data processing' section for more details). The used LULC database for the southern and eastern countries of the Mediterranean basin was developed in the framework of the GlobWetland-II project (GW-II 2010–2014, funded by the European Space Agency) and completed by the Mediterranean Wetlands Observatory (Tour du Valat) for the northern shore. All LULC (for 1990 and 2005) were derived from Landsat time series (see Perennou et al. (2018) and Beltrame et al. (2015) for methods). The LULC classes were defined using a hybrid nomenclature that combines both CORINE Land Cover (CLC) and Ramsar definitions (see S1). Out of the 305 sites covered by the GW-II/MWO database, 164 were also monitored for mid-winter waterbird populations between 1991 and 2010 following a specific guideline (Delany 2005).

Concerning climate data, all following calculations were done according to Karger et al. (2017) methodology. To process the annual mean temperature (Tmean), we used the monthly average of the mean temperature across the studied period (from 1986 to 1995 and from 2001 to 2010). We extracted the monthly mean value of each cell using ArcGIS (spatial analyst tool, Cell Statistic by Mean). To get the maximum or minimum temperature of the warmest or coldest month (Tmax and Tmin), we processed the monthly average of the mean, maximum, or minimum temperature across the studied period (from 1986 to 1995, and from 2001 to 2010). Like previously, we used the Spatial Analyst tool on ArcGIS (Cell Statistic by Maximum or Minimum) to extract the monthly maximum or minimum value of each cell. Regarding the temperature seasonality (Tseas), we used monthly temperature mean available from CHELSA by applying the standard deviation: sd(monthly temperature) × 100 (see available code). The annual precipitation (Pmean) was obtained by calculating the sum of the monthly averages of the precipitation across the studied period (from 1986 to 1995 and from 2001 to 2010) using the Spatial Analyst tool on ArcGIS (Cell Statistic by Sum). The precipitation of the driest or wettest months (Pdry and Pwet) was determined using the monthly average of the minimum precipitation across the studied period (from 1986 to 1995 and from 2001 to 2010). To extract the monthly maximum (wettest month) or minimum (driest month) value of each cell, we used the Spatial Analyst tool on ArcGIS (Cell Statistic by Maximum or Minimum). Finally, the precipitation seasonality (Pseas) was obtained by computing the coefficient of variation [sd(monthly precipitation, e.g. from 1986 to 1995) / (1 + mean(monthly precipitation, e.g. from 1986 to 1995))] × 100 (see available code).

Statistical analysis

We used a partial triadic analysis (PTA) (Thioulouse et al. 2004) to perform a site-specific assessment taking into account changes in climate and land cover between 1990 and 2005, considering the first three axes. PTA is a multivariate technique similar to a principal component analysis (PCA) that integrates three dimensions such as variables, sites (as PCA), and time. To account for changes, we extracted Euclidean distances between 1990 and 2005 to obtain a 'vector of change' (VoC) for each variable and each site across the first three axes of the dimensional space, as well as the changes that occurred for each variable combining all sites. The climate and land cover change indicators were assessed with VoCs using either the eight climatic variables or the four land cover variables related to pressure, excluding the extent of natural wetland habitats, considered here as a dependent variable. This allowed us to assess which variables were changing the most within the Mediterranean basin within each climate or land cover change indicator. We made a site characterisation of the wetlands using the compromise between 1990 and 2005 (Figure S1). We also assessed the conversion of the land cover extent between the 2 years by using the remote sensing software 'GEOclassifier' (see https://www.swos-service.eu/documents_mapping-software/) to produce a conversion matrix (Table S2).

We identified the factors that can affect natural wetland habitat loss or waterbird diversity (beta-Sorensen and Simpson diversity) by the use of generalised linear models and beta-regression, respectively. Each climate variable's change (e.g. Tmean diff), land cover variable PoC (e.g. Tmean PoC), climate, and land cover VoC were tested as explanatory variables. We finally assessed if most of the changes occurred predominantly in unprotected or protected sites (no, low, and high coverage) using a Kruskal-Wallis test combined with the Conover post hoc test (Conover and Iman 1979). Changes in climate and land-use such as agricultural expansion are expected to have severe consequences on bird populations (Stephens et al. 2016; Green et al. 2005). Therefore, we tested a change among each climate variable, land cover variable PoC, climate and land cover VoC, natural wetland loss, beta-Sorensen, and Simpson diversity. Considering natural wetland habitat loss, we selected all negative values of the initial natural wetland habitat percentage of change (discarding 36 sites out of the 236, among which 31 did not experience any change) divided by minus a hundred to produce normalised values between 0 and 1. We fitted a generalised linear model with binomial distribution to the data. The residuals from the beta-Sorensen metric followed a negative beta-distribution with [0;1] values that we fitted with a beta-regression model (logit link), while the ones from the Simpson diversity metric followed a Gaussian distribution and were then fitted using a linear model.

Multivariate and statistical analyses were performed using R with ade4 and betareg packages. The current methods are suitable for any ecosystem type to assess the overall changes at diverse scales, regions, and cases of study.

Results

Of the 236 studied sites, 119 (50%) have most of their area covered by a protection status while for 78 (33%), no protection was reported. Most of the wetlands with high protection coverage are located in Southern Europe, while sites in the Maghreb or Near East regions of the Mediterranean predominantly have low or no protection coverage (Fig. 1). Within the 15 years analysed, the area of natural wetland habitats declined by 5% in the studied sites (Fig. 1b).

When comparing patterns in changes in mean temperature and precipitation between 1990 and 2005 (Fig. 1), our results showed that 50% of the studied wetlands experienced a temperature increase above 0.6 °C reaching a maximum of 1.1 °C, and 70.6% of the sites experienced a decrease in precipitation (Fig. 1a). Warming occurred mainly in the southeast of the Mediterranean where simultaneously most of the unprotected sites are located (Fig. 1 and S1). Our results also indicate a decrease in precipitation in the southeast through the years (Fig. 1) which is consistent with an increase in drought events and reduction of water availability in this area, as detected by other studies (Mariotti et al. 2008).

Wetland sites were directly impacted by the overall increase of land cover change (VoC) mainly driven by agriculture and urbanisation (Fig. 2a), while natural wetland habitats

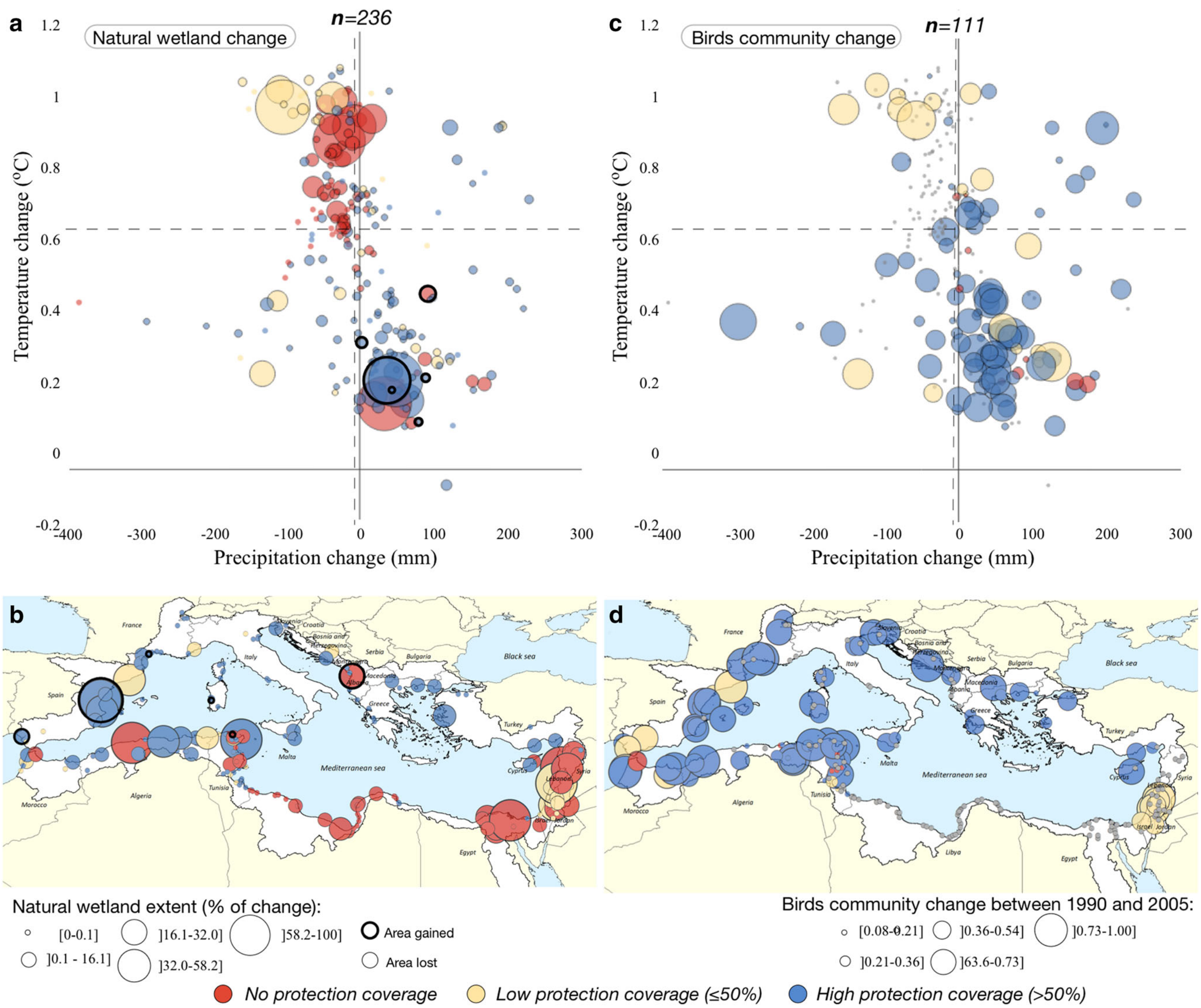

Fig. 1 **a** Proportion of natural wetland habitat change per site in 2005 compared with 1990 along the mean temperature and mean precipitation change gradients. The bubble size represents the percentage of change (PoC) of the natural wetland habitats within each wetland site. The outlines represent the direction of change of the natural wetland habitats extent: bold outlines show a positive change (gain), light outlines a negative change (loss), and the smallest bubbles with no outlines indicate no change. **b** Geographical layout of natural wetland change. **c** Beta-Sorensen values of waterbirds per site between 1990 and 2005 along the mean temperature and mean precipitation change gradients. The bubble size represents the beta-Sorensen values (from 0 to 1) representative of community change within each wetland site. **d** Geographical layout of the beta-Sorensen values. The colours represent the protection status of the sites such as red means no protection status ([0] in barplot), yellow means low protection coverage ([0–50] in barplot), blue means high protection coverage ([50–100] in barplot), and grey means sites without species data available, and the associated number of sites on the barplots that are present within medians delimitations (dashed lines)

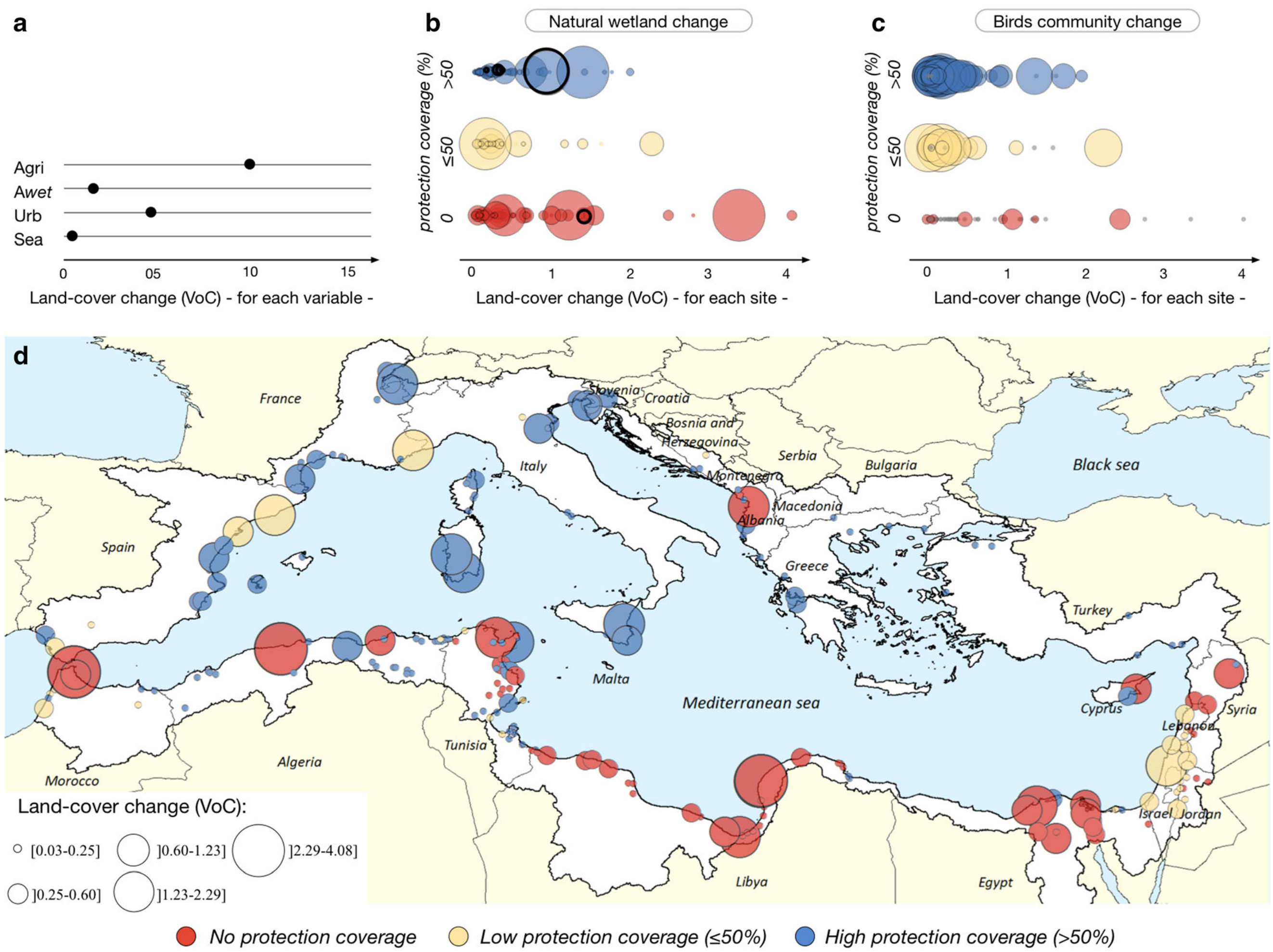

Fig. 2 Partial triadic analysis to assess the change occurring among land cover variables in 1990 and 2005. As land cover variables, we considered agricultural (Agri), artificial wetland habitats (Awet), urban (Urb), and sea (Sea) areas. The importance order of the vector of change (VoC, with high value for high land cover change) of each variable between 1990 and 2005 is represented in (**a**). The other top panels represent each site along the land cover VoC gradient with bubble size accounting for natural wetland percentage of change (PoC) (**b**) and beta-Sorensen metric of waterbird species (**c**). The lower panel **d** shows the spatial distribution of wetland sites experiencing a greater or lesser degree of land cover change as represented by the bubble size (climate VoC). The protection coverage is represented by a colour code

were mostly replaced by agricultural areas (2.6%), artificial wetlands (2.1%), and urban areas (0.3%) (Table S2). The sites with high protection coverage were significantly less affected by natural wetland habitat loss than sites with low or no protection coverage (Kruskal-Wallis, $X^2 = 11.76$, df = 2, $p < 0.01$, Table S5). In a few sites, we detected an increase in natural wetland habitats mainly due to restoration actions (e.g. Caracoles Estate in Doñana Santamaria et al. (2006)). Our analysis shows that among a larger set of climate variables, the overall impact of climate change (VoC) on Mediterranean wetlands was mostly determined by changes in the different dimensions of temperature (i.e. minimum, maximum, and seasonality; Fig. 3a).

Regarding the waterbird species, neither Sorensen beta-diversity nor Simpson diversity showed a significant response to the climate or land cover change at site level (Table S4), with the exception of a significant decrease in species turnover with increasing maximum temperatures. Even though the spatial pattern of species diversity and turnover was relatively homogeneous across sites (Fig. 1d, Figure S2), species turnover was higher for sites benefitting from protection coverage (Kruskal-Wallis, $\chi^2 = 10.88$, df = 2, $p = 0.00$, two-tailed, Table S5). Also, there is a substantial geographical bias in the distribution of waterbird monitoring programmes towards areas with higher protection coverage, with none of them located in the Near East where a signal for high species turnover occurred (Fig. 1d and S4).

Discussion

Through climate and land cover change indicators, we identified areas within the Mediterranean basin where wetlands were the most exposed to changes. The use of such indicators could

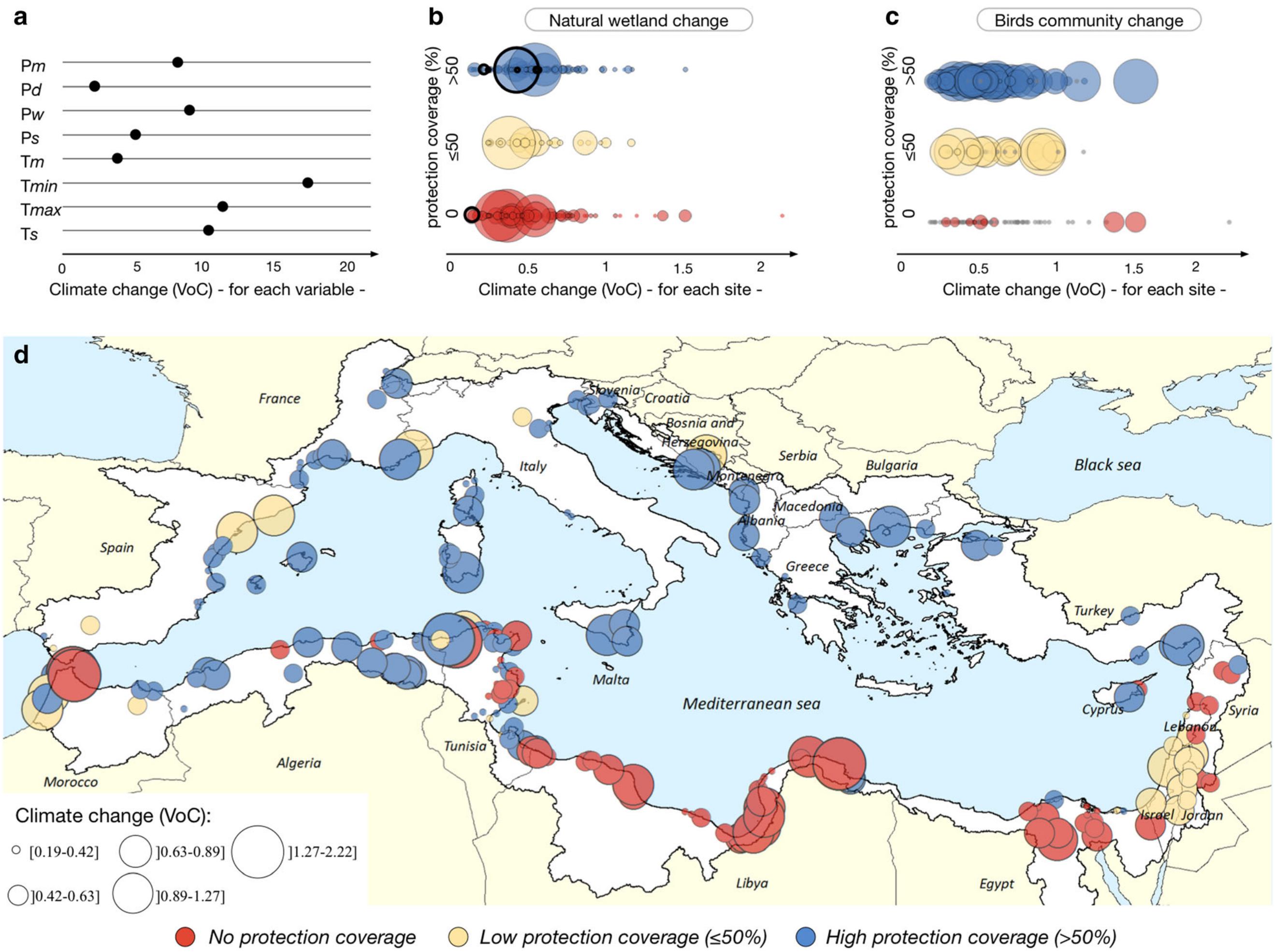

Fig. 3 Partial triadic analysis to assess the change occurring among climate variables in 1990 and 2005. As climate variables, we considered annual temperature and precipitation mean (Tm, Pm), temperature and precipitation seasonality (Ts, Ps), maximum temperature of the warmest month (Tmax), minimum temperature of the coldest month (Tmin), and precipitation of the driest and of the wettest month (Pd, Pw). **a** The importance order of the vector of change (VoC, with high value for high climate change) of each variable between 1990 and 2005. The other top panels represent each site along the climate VoC gradient with bubble size accounting for natural wetland percentage of change (PoC) (**b**) and beta-Sorensen metric of waterbird species (**c**). The lower panel **d** shows the spatial distribution of wetland sites experiencing a greater or lesser extent of climate change as represented by the bubble size (climate VoC). The protection coverage is represented by a colour code

be extended at global scales, as they rely on satellite data. We found that the Near East region has lost a large proportion of natural wetlands because they were the least well covered by protection measures and were subject to the strongest effects of climate change. Unsustainable water use aggravated by extreme drought episodes has already led to quite adverse conditions, raising major concerns towards wetland sites and human well-being (Kelley et al. 2015; Levin et al. 2009). Moreover, a major data gap towards unprotected sites did not allow us to draw solid conclusion towards any effect of wetlands' protection coverage on waterbirds. Across the Mediterranean, natural wetland habitats were mostly replaced by agricultural areas, artificial wetlands, and urban areas.

Mean temperature and precipitation only cover part of the climatic complexity and variance (e.g. they tell little about variabilities in climatic extremes). Indeed, small changes in some variables can have significant impacts, depending on the sensitivity of the ecosystem. For instance, a small increase in the number of sea intrusions can severely alter the long-term salinity of coastal wetland systems (Herbert et al. 2015). The use of a climate change indicator by quantifying the degree of change of each input variable could help in explaining the urgency for adaptations of water use.

Waterbird species turnover was higher in protected sites. This suggests a link to the recovery of depleted populations (Gardner et al. 2015; Kleijn et al. 2014) that could also mask the impact of climate and land cover change. The low number of significant impacts of each climatic and land cover factor on waterbird turnover can be partially explained by the fact that there is a substantial geographical bias in the distribution of waterbirds with data records mainly present in areas benefiting a protection coverage. Furthermore, a reduction of natural wetland habitats does not imply a reduction of available water surface, because the construction of dams and reservoirs can result in an increase of artificial wetland habitats, as it was the case in the Mediterranean basin between 1984 and 2015 (Pekel et al. 2016; Geijzendorffer et al. 2018). Artificial water bodies can partly replace natural water bodies in the total available habitat for waterbirds, dampening the noticeable impact of natural habitat loss on these species. These data constraints limited our analysis in comparison with previous studies that found an accelerating loss of the Eastern Mediterranean bird populations using the Living Planet Index (Galewski et al. 2011). A more accurate monitoring of biodiversity trends could be achieved by a better partitioning of monitoring across protected and unprotected sites. The Mediterranean Waterbird Network, which assists in the implementation of the Ramsar Convention and the African-Eurasian Waterbird Agreement in the Mediterranean region, recognised this issue and is currently strengthening waterbird monitoring in North Africa (Sayoud et al. 2017).

Birds are one of the most studied wildlife, often used as ecological indicators. However, despite the spread of waterbirds across a wide range of trophic levels and habitat characteristics, they are mainly hibernating and/or migratory species, breeding outside the Mediterranean. Thus, the impact of climate and land cover change can be relative as birds are not here all year. Moreover, waterbirds are probably not reflecting all consequences of the environmental changes for fish, reptiles, or invertebrate species. For example, dam creation could increase deep-waterbird populations but could also cause collapse of migratory fish and shallow water invertebrate populations. Also, integrating data on other species groups (e.g. endemic amphibians and fishes) that are more vulnerable to the degradation of wetland habitats than waterbirds, or the use of distinct habitat features (e.g. temporary ponds or water courses), would add relevant information on wetland ecosystem states (Cuttelod et al. 2009). Moreover, at a local level, wetlands depend on complex hydrological cycles that go beyond site boundaries, partly determined by groundwater and stream networks. Therefore, a site-based approach can reach limitations without the consideration of buffer zones that integrate areas of major importance for the studied system (e.g. watersheds). Some specific variables outside the wetland sites should be monitored for their potential impact on the water system (e.g. distance to settlements, number of dams, population density, and agricultural areas).

Wetland areas are affected by a wide range of pressures and data availability or resolution did not allow us to include data on specific pressures (i.e. water availability, water use, water quality, infrastructure construction (dams), population density). In this sense, much of the information mentioned by Turak et al. (2017) is still needed to achieve a most comprehensive assessment. This includes information not only about the wetland sites themselves but also about the upstream system that regulates many of the local ecological functions and interactions. Their identification can be used to launch or orient systematic monitoring programmes to identify wetland degradation and their conservation threats.

By using environmental variables in a regional assessment of wetlands, we demonstrated the mismatch between hotspots of climate change, land-use change, and habitat protection coverage within the Mediterranean basin. Our approach coupled with multivariate techniques assessed the exposure of sites to different threats that can inform strategic decision-making and identify biases in monitoring efforts. The selected variables did not allow us to establish real causality of the changes perceived, as the studied drivers are only part of a wide range of aspects of global change. Facilitating better decision-making for the conservation of wetlands relies on evidence of exposure to pressure as well as understanding the associated causality links.

Conclusions

In this study, we demonstrated that within the Mediterranean basin, unprotected wetlands from the Middle East countries were the most exposed to climate changes. Natural wetlands are intimately linked to surface and ground water provisioning and purification, and their disappearance will deprive human livelihoods of these important services (Fan et al. 2013). Therefore, natural wetlands loss in arid regions can have disastrous consequences on freshwater reserves. Climate change with a regime of reduced precipitation and increased temperature (0.5 to 1.0 °C annual mean relative to the twentieth century average) already has had dramatic effect in the Eastern Mediterranean on water resources and so crop production, which has contributed to severe conflicts (Kelley et al. 2015). However, effective policies and management strategies will be able to mitigate the adverse effects of climate change and agricultural water needs on the risk of wetland desiccation the effect of climate change combined with land-use water needs regarding wetland ecosystems risk of drought can be buffered by effective policy and management. As 'water rights' are a shared issue among stakeholders, socio-ecological systems promoting the dialogue between the different players can be successful if the required use of wetlands by wildlife can be a starting point in negotiations (Downard et al. 2014). This integrative approach presented here stresses the importance of species monitoring to produce metrics (i.e. wildlife habitat) as a tool for policy in water right negotiations and enhances the understanding of the system to maintain wetland resilience to drought through forecasting. In addition, ecosystem-based approaches to adaptation that promote the use of targeted ecosystem services to reduce system exposure to disturbances—such as the benefit of coastal marshes in dissipating storm energy flow along exposed coastlines—are gaining attention (Jones et al. 2012). A combination of both approaches with a complementary agricultural policy that encourages the production of crops compatible with low water availability during periods susceptible to encounter severe droughts could help to maintain wetland health and functioning under climate change. Implementing such concepts is nevertheless challenging in the Mediterranean countries that come across diverse level of governance stability and functioning.

The current study provides an integrated large-scale regional assessment of Mediterranean wetlands that can inform local decision-makers on their state and trends, emphasising the sites where actions for climate change mitigation (Downard et al. 2014; Jones et al. 2012) or potential protection are required. Our approach has delivered a simple and reliable overview of wetland state, recognising that there are still considerable opportunities for improvement regarding variable selection and data collection. Wetland sites with important conservation values face a number of barriers that hamper their ability to achieve their conservation goals, such as limited means, capacity, and political priority. The use of globally widely available data, such as remote sensing data, could be part of the solution to at least provide information of some relevant variables at play for wetland conservation.

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