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Preserving the Mediterranean bird flyways: Assessment and prioritization of 38 main wetlands under human and climate threats in Sardinia and Sicily (Italy)

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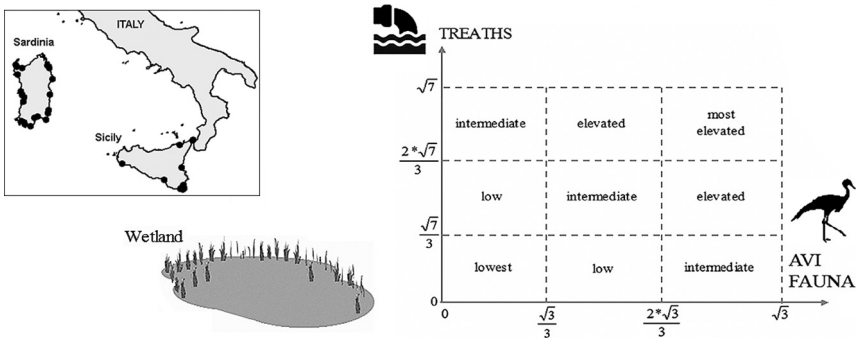
HIGHLIGHTS

- Wetlands provide the stopover sites that allow waterbirds to make migratory journeys.
- We evaluated and prioritized 38 main wetlands in Sardinia and Sicily (Italy).
- The Sardinian wetlands resulted mainly threatened by human activities.
- The Sicilian wetlands resulted primarily endangered by climate change.
- We suggest urgent interventions on these sites along the Mediterranean bird flyways.

GRAPHICAL ABSTRACT



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ABSTRACT

Wetlands provide a wide range of ecosystem services, including supplying the food and shelter for a rich assemblage of waterbirds and providing the stopover sites that allow birds to make migratory journeys. Human impact and the ongoing climate change are however reducing the ability of wetlands to provide such important services. Through field surveys, GIS analyses and climate projections, we assessed the status of, and threats to, 38 largest wetlands belonging to the Mediterranean bird flyways in Sardinia and Sicily (Italy). We then combined ten decision criteria about avifaunal diversity and human/climate threats in order to prioritize the studied wetlands from most to least worthy of urgent interventions.

Results showed that the main wetlands of these two regions have distinct demands with regard to the kind of actions required, going from the mitigation of tourism pressure to the prevention of climate-induced water shortage in summer. Furthermore, clear priorities for interventions emerged in both regions.

Our study has direct implications for managers and researchers attempting to assess wetland conditions and set conservation priorities, thus offering a tool for deciding urgent interventions on the main stopover sites along the Mediterranean bird flyways.

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1. Introduction

Wetland ecosystems are declining worldwide, and more than half of the world's wetlands have been altered, degraded or lost in the last 150 years (Gardner et al., 2015). Tourism, agricultural expansion and urban development are recognized as some of the major causes of this decline (Baker et al., 2007; Mitsch and Gosselink, 2015). Farming activities generally overuses water for irrigation, often resulting in water shortage and pollution due to the use of fertilizers and pesticides (Jensen et al., 2008; Beaumont and Duursma, 2012). Tourist activities can exert a considerable influence on wetland integrity and biodiversity levels as well

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(Hoover, 2009; Gardner et al., 2015). The increased transport by air, road, and rail can contribute to severe local air pollution (Mitsch and Gosselink, 2015), whereas construction of recreation areas and other facilities can lead to increased sewage and waste water pollution (Gardner and Finlayson, 2018). Tourism facilities can also involve sand mining, beach and sand erosion, soil erosion and extensive paving (Gardner et al., 2015). Recreational activities (e.g. hunting and fishing activities, free camping, sound and light emissions, etc.) can lead to severe impacts on wetlands and the associated biodiversity, such as the intentional removal of waterbirds by direct kill, the poisoning due to discarded litter and lead shots used for hunting, the damage to nests, noise disturbance leading to reduced breeding success and modified habitat use (Kirby et al., 2004). The ongoing climate change, with warmer and dryer summer periods, poses an additional threat to water availability, and will exacerbate the risk of complete drainage of wetlands in summer (Johnson et al., 2005; Erwin, 2009). The resulting water level fluctuation and change in water depth may affect the use of wetland habitats by many waterbird species (Kaminski et al., 2006). Climate-induced sea level rise will increase the risk of permanent saltwater intrusions in coastal wetlands (Bailey et al., 2006). The increased evaporation, combined with saltwater intrusions, will cause natural salinity levels to be high for long periods of time, thus altering the chemical and physical environment of wetlands with the potential to alter ecosystem-level processes, decrease the species richness of most biological groups, and impact the valuable ecosystem services provided by wetlands (Barlow and Reichard, 2010).

Natural wetlands supply the food and shelter for many waterbird species (Darnell and Smith, 2004), and provide the stopover sites that allow waterbirds to make migratory journeys that primarily depend on the integrity of the whole wetland network (Fraser and Keddy, 2005; Kelly et al., 2008). Birds usually choose intermediate stopover sites along the migratory flyways to rest and refuel (Studds et al., 2017). Italy is natural bridge between Europe and Africa, therefore representing a flyway of elevated importance for a wide number of bird species confronted with the crossing of the Mediterranean (Berthold, 2001). Besides migratory bird species, wetlands also support a whole range of waterbirds that choose to avoid migration and remain at wintering grounds located close to breeding areas, therefore resulting important also for breeding, moulting and wintering purposes (Keddy, 2006). Sicily (25,718 km^2) and Sardinia (24,100 km^2) are the largest islands in the Mediterranean sea, and their wetlands represent a network of important stopover sites along the Mediterranean flyways (ISPRA, 2008). Therefore, the conservation and management of wetlands in Sicily and Sardinia is pivotal for many avian species, in particular passeriforms, ducks in winter, waders in summer and autumn.

Accordingly, in this work we present the assessment and prioritization of 38 main (i.e. largest) wetlands in Sardinia and Sicily (Italy) under human and climate threats. Wetland assessment (Finlayson, 2003) is the identification of the status of, and threats to, wetlands as a basis for successive analyses and decision modelling. Wetland prioritization (Widis et al., 2015) is the process of ranking the studied wetlands from most to least worthy of urgent interventions for the mitigation, compensation or prevention of threats, based on the previous assessment phase. We focused our study on the summer period, when water scarcity and tourism pressure are at their peak, therefore corresponding to the most critical span of time for waterbirds. Our study is aimed to provide managers and administrators with a tool for choosing proper and urgent interventions on the stopover sites of utmost importance along the Mediterranean bird flyways.

2. Methods

2.1. Selection of the study areas

In order to limit our efforts to wetlands with effective support to avian diversity, we used three selection criteria: a) surface area: 10 ha (1 ha = 10,000 m^2); b) exclusion of artificial wetlands (e.g. rice paddies, fish and shrimp ponds, farm ponds, salt flats etc.); c) spatially homogeneous occurrence along the coastline of the two regions (as much as permitted by their spatial distribution). The latter criterion was motivated by the fact that degradation of coastal wetlands accelerated more than that of inland ones in the twentieth century, and coastal wetlands are also more potentially impacted by climate change (Keddy, 2006). Besides, in both regions almost all the inland wetlands are artificial, and the few natural ones did not meet our first criterion.

Therefore, we selected 22 wetlands (average distance among wetlands = 12.6 km) in Sardinia and 16 (average distance = 11.8 km) in Sicily (Fig. 1; Suppl. Figs. S1–S2). The total surface area of the selected areas was 5545 ha in Sardinia and 676 ha in Sicily. In Sardinia, 16 out of 22 wetlands belong to the Natura 2000 network (in either of the following forms: special protection area, site of Community interest, special area of conservation), in Sicily 15 out of 16.

2.2. Assessment of avifaunal diversity

The avian biodiversity was evaluated in summer (July–September 2016). The rationale behind this choice was double. First, summer is the most critical period of the year for wetlands and the associated biodiversity due to the marked increase in tourism pressure and water scarcity. Second, as wetlands in Sardinia and Sicily belong to the Mediterranean bird flyway, in summer they host the highest number of avian species and individuals, in particular waders in migration towards sub-Saharan Africa. Accordingly, we focused our assessment of avifaunal diversity on the time interval that is most critical and important for conservation.

For each wetland we used regularly-spaced sampling points (whose amount was proportional to the wetland extent, and up to a maximum of 12 points) with 200-m minimum distance among points in order to minimize spatial autocorrelation (Griffith, 1987). In total, we used 144

Fig. 1. The 38 wetlands under study in Sardinia and Sicily (Italy).

Table 1
List of the ten criteria used for wetland assessment and prioritization. Field surveys were carried out from July to September 2016.

Criterion	Code	Data type	Unit	Source
A) Avian diversity				
Number of species	BIO1	Continuous	Unitless	Field surveys
Number of individuals	BIO2	Continuous	Unitless	Field surveys
Importance for conservation	BIO3	Continuous	Unitless	Field surveys
B) Threats				
B1) Current threats				
Recreational/tourism pressure	THR1	Discrete (0-1-2-3)	Unitless	Field surveys
Water pollution discharges	THR2	Discrete (0-1-2-3)	Unitless	Field surveys
Water diversion	THR3	Discrete (0-1-2-3)	Unitless	Field surveys
Anthropization	THR4	Discrete (0-1-2-3)	Unitless	Field surveys
B2) Future threats				
Anthropization processes in the surroundings	THR5	Continuous	%	GIS analyses
Saltwater intrusions by 2040 due to sea level rise	THR6	Discrete (0-1)	Unitless	Climate modelling
Water shortage in summer by 2040 due to increased evaporation	THR7	Continuous	%	Climate modelling

sampling points for the Sardinian wetlands, and 58 in Sicily (Suppl. Tables 1–2). We employed the standard point count sampling method (Hutto et al., 1986), which required 100-m observation distance around each sampling point and 15-min observation time with recording of all visual or vocal contacts. Biodiversity sampling was carried out before the assessment of threats (Section 2.3) so as to avoid disturbance on avifauna and, thus, biases in the sampling process.

For each wetland, we used three criteria of avian diversity (Table 1): 1) average number of bird species (BIO1) and 2) individuals (BIO2), 3) a score of importance for avian conservation (BIO3) in the form of composite index of SPEC (BirdLife International, 2017) and Global Red List (available at https://www.iucnredlist.org) values. A weight w_i of importance for conservation was assigned to each species (Table 2), then BIO3 was computed as average w_i.

BIO1 and BIO2 measured the quantitative component (species richness and abundance) of the avifauna present in the studied wetlands, BIO3 the qualitative one (importance for conservation). We carried out six sampling sessions (with interval of about 15 days between successive sessions) from mid-July to the end of September 2016, and for each criterion we used the average value of the six measurements in order to account for all the summer period. The list of the bird species sampled in the wetlands of the two regions is presented in Suppl. Table 3.

Table 2
We used a composite SPEC-Red List index to weigh the importance for conservation of the sampled bird species. The SPEC index was considered hierarchically more important because it is focused on species importance at European level. Although all the combinations between SPEC and Global Red List were possible, we only detected species belonging to the combinations marked with an asterisk in the following list. SPEC 1 = European species of global conservation concern; SPEC 2 = species with global population concentrated in Europe and with unfavorable conservation status in Europe; SPEC 3 = species not concentrated in Europe but with unfavorable conservation status in Europe. Key to reading: a species was given weight equal to 34 if it belonged to the SPEC 1 level of importance and, simultaneously, it was considered critically endangered by the Global Red list.

SPEC	Global Red List	Weight
1	Critically endangered	34
	Endangered	33
	Vulnerable *	32
	Near threatened *	31
	Least concern	30
2	Critically endangered	24
	Endangered	23
	Vulnerable	22
	Near threatened	21
	Least concern *	20
3	Critically endangered	14
	Endangered	13
	Vulnerable	12
	Near threatened	11
	Least concern *	10
Non-SPEC	Critically endangered	4
	Endangered	3
	Vulnerable	2
	Near threatened	1
	Least concern *	0

2.3. Assessment of threats

2.3.1. Current threats

We used four criteria for measuring threats acting upon the selected wetlands (Table 1). We carried out field surveys in the close surroundings of the selected wetlands to detect the levels of: 1) recreational/tourism pressure (i.e. tourist activities like walking, horse riding, water sports, angling, wildfowling etc.; THR1), 2) water pollution discharges (THR2), 3) water diversion for farming activities (THR3); 4) anthropization (occurrence of greenhouses, dumpsites, quarries, camping sites, caravan parks etc.; THR4). We assigned scores on a semi-quantitative scale of 0 to 3 (0 = absent, 1 = low, 2 = intermediate, 3 = elevated) to each threat, using both technical (i.e. the authors) and local (i.e. the natives, local policymakers and landowners) knowledge of the studied wetlands. Each expert provided an independent score for each threat (0 if it was absent, 1 if localized, 2 if scattered, 3 if widespread). In the few cases where there was no agreement, on a precautionary basis we selected the most elevated score among those provided by the experts.

As for the assessment of avian diversity, our estimation of the current threats was focused on the summer period (July–September 2016) for the reasons explained above, thus different levels of these threats could be present in other periods of the year.

2.3.2. Future threats

We used three criteria for quantifying the future threats to the selected wetlands (Table 1): 1) risk of anthropization processes in the surroundings (THR5), 2) risk of permanent saltwater intrusions by 2040 due to climate-induced sea level rise (THR6), 3) risk of water shortage in summer by 2040 due to the climate-induced increase in evaporation (THR7).

To assess the risk of future land use/land cover (LULC) transition processes leading to the anthropization of the close surroundings, we used the available spatial datasets describing LULC in 2006 and 2012 for both Sardinia and Sicily, available from the ISPRA (Italian National Institute for Environmental Protection and Research) website (*http://www.sinanet.isprambiente.it/it/sia-ispra/download-mais/corine-land-cover*, accessed April 23, 2019), where the two regions are classified in vector format in compliance with the European Corine Land Cover project (EEA, 1995). Within GIS, we created a 2-km buffer zone around each wetland and calculated the

percentage of the buffer that shifted from natural (forest, semi-natural and wetland areas) to artificial (developed and agricultural areas) in the recent 2006–2012 period. We used this percentage as proxy to quantify the risk of further anthropization processes around each wetland in the next future.

During the 1993–2018 period, the climate-induced sea level rise had an average velocity of 3 ± 0.4 mm/year, and an acceleration of 0.033 mm/year^2 to 0.084 mm/year^2 is to be expected in the future under moderate and extreme scenarios, respectively (Nerem et al., 2018). Following these indications, we calculated that a cumulative increase of 7.4 to 8.5 cm in the sea level is to be expected by 2040 under moderate and extreme scenarios (Suppl. Fig. S3). Thus, for each wetland we assessed the risk of permanent saltwater intrusions by 2040 due to sea level rise set precautionarily equal to 10 cm. For each wetland, we observed: a) distance from nearest coastline, b) height of natural dune cordons and c) artificial barriers that are present (if any) between wetland and sea. We then assigned a binary score (0 = absent, 1 = present) to each wetland in order to quantify the risk of permanent saltwater intrusions by 2040.

To assess the risk of future water shortage in summer, for each wetland we estimated the expected decrease (in mm) in water depth by 2040 (W_{2040}) due to changes in evaporation (E; in mm) and rainfalls (R; in mm) in June, July, August and September as

$$\Delta W_{2040} = \sum_{k=June}^{September} \Delta E_k + \sum_{k=June}^{September} \Delta R_k$$

We used datasets for the extreme (RCP8.5) short-term (2011–2040) climate scenario (Suppl. Tables S4–S5) from the recent IPCC Fifth Assessment Report (IPCC, 2013), and employed ensemble projections averaged across 15 Coupled Model Intercomparison Project Phase 5 (CMIP5) models (CanESM2, ACCESS1.0, IPSL-CM5AMR, MIROC5, MPI-ESM-LR, CCSM4, HadGEM2-ES, CNRM-CM5, CSIRO Mk 3.6, GFDL-CM3, INM-CM4, MRI-CGCM3, MIROC-ESM, CESM1-CAM5, GISS-E2R) to account for the uncertainty in the climate predictions. Changes in summer rainfalls (i.e. ΔR) were directly calculated from RCP8.5 2011–2040 data. In order to calculate changes in summer evaporation (i.e. ΔE), we applied the Thornthwaite equation (Thornthwaite, 1948) to changes in summer temperatures under the RCP8.5 scenario (Suppl. Text. S1; Suppl. Tables S6–S7). We then calculated the expected decrease in water depth with respect to current water levels (i.e. average water depth measured in 2016 during six field surveys; W_{2016}) as

$$\Delta_{\%} W = 100 * \frac{\Delta W_{2040}}{W_{2016}}$$

2.4. Wetland prioritization

Multicriteria analysis (MCA) is a set of methods and procedures for evaluating decision alternatives on the basis of multiple attributes (Voogd, 1983). Ideal Point Method (IPM) is one of the most commonly used MCA techniques (Zeleny, 1982). Using IPM, we evaluated and ordered the decision alternatives (i.e. wetlands) based on their distance from the ideal or anti-ideal point, i.e. a hypothetical alternative that consists of the most desirable/undesirable levels for j criteria (i.e. avifaunal diversity and current/future threats). The overall aim of IPM was to find the alternatives that come as close as possible to the ideal alternative, or as distant as possible to the anti-ideal one.

Through normalization, criteria lose their dimension and their value ranges become comparable, thus we applied a standardization procedure based on "min–max normalization" (i.e. $(x_{ij} - \min x_j) / (\max x_j - \min x_j)$). We then used IPM to build two composite indices for each wetland: AVIFAUNA and THREATS. The former index represented the distance of the generic i-th wetland to the hypothetical alternative consisting of the most undesirable levels of avian biodiversity, and was computed as

$$AVIFAUNA_i = \sqrt{\sum_{j=1}^{3} \left(c_j^i - c_j^{\min}\right)^2}$$

where c_1, c_2 and c_3 are the three avifauna criteria, and the term under the square root represents the Euclidean distance of the i-th wetland from the anti-ideal alternative for avifauna. As data have been standardized using "min–max normalization", it can be easily demonstrated that AVIFAUNA$_i$ potentially ranges from 0 (i.e. the wetland under study had the lowest levels of the avian criteria among the wetlands of its region) to $\sqrt{3}$ (= 1.73; i.e. highest levels of all the 3 avian criteria). The $[0-\sqrt{3}]$ interval allowed us to separate the studied wetlands into 3 equi-intervals of avifaunal diversity: "low" if AVIFAUNA$_i$ was between 0 and 0.58, "intermediate" between 0.58 and 1.16, and "elevated" between 1.16 and 1.73.

The THREATS index represented the distance of the generic i-th wetland to the hypothetical alternative consisting of the most desirable levels of threats, and was computed as

$$THREATS_i = \sqrt{\sum_{j=1}^{7} \left(c_j^i - c_j^{\min}\right)^2}$$

where $c_1 \ldots c_7$ are the seven criteria of threats, and the term under the square root represents the Euclidean distance from the ideal alternative for threats. As data have been standardized using "min–max normalization", THREATS$_i$ potentially ranges from 0 (i.e. the i-th wetland had the lowest values of all the 7 threats among the wetlands of the region) to $\sqrt{7}$ (= 2.64; i.e. highest values of all the 7 threats). The $[0-\sqrt{7}]$ interval allowed us to separate the wetlands into 3 equi-intervals of threats: "low" if THREATS$_i$ was between 0 and 0.88, "intermediate" between 0.88 and 1.76, and "elevated" between 1.76 and 2.64.

We then built the decision space for wetland prioritization in the form of a biplot for cross-tabulation of AVIFAUNA and THREATS (Fig. 2). The most elevated priority was assigned to wetlands with elevated scores on both indices. We followed the easily defensible rationale that elevated priority should be assigned to those wetlands where valuable stocks of avian diversity resulted jeopardized by high levels of current and future threats. Elevated priority was given to wetlands with a) elevated AVIFAUNA and intermediate THREATS, or b) intermediate AVIFAUNA and elevated THREATS. Intermediate priority was assigned to wetlands with intermediate scores on both indices, whereas low priority to wetlands where avian biodiversity was low (i.e. little to be preserved) or threats were low (little to be mitigated, compensated for, or prevented). The lowest priority was assigned to wetlands with low values on both indices.

3. Results

3.1. Sardinia

Two wetlands, Pilo (BIO1 = 138.4, BIO2 = 6.8) and S. Giovanni (BIO1 = 177.3, BIO2 = 6.1; Table 3; Suppl. Fig. S4) scored the highest values for two criteria of avian diversity out of three. Feraxi (BIO3 = 7.4) and Tartanelle (BIO3 = 6.4) had the highest scores for the importance of conservation of the sampled species. Sa Curcurica (BIO1 = 1.3, BIO2 = 0.4, BIO3 = 0) scored the lowest values for all the criteria of avian diversity.

Tourism pressure was elevated in four (THR1 = 3; Calich, S. Teodoro, Tartanelle, Tortoli) out of 22 wetlands (Suppl. Fig. S5), and intermediate in further seven (THR1 = 2; Chia, La Maddalena, Notteri, Pilo, Porto Botte, S. Giusta, Sa Curcurica). We detected intermediate pollution

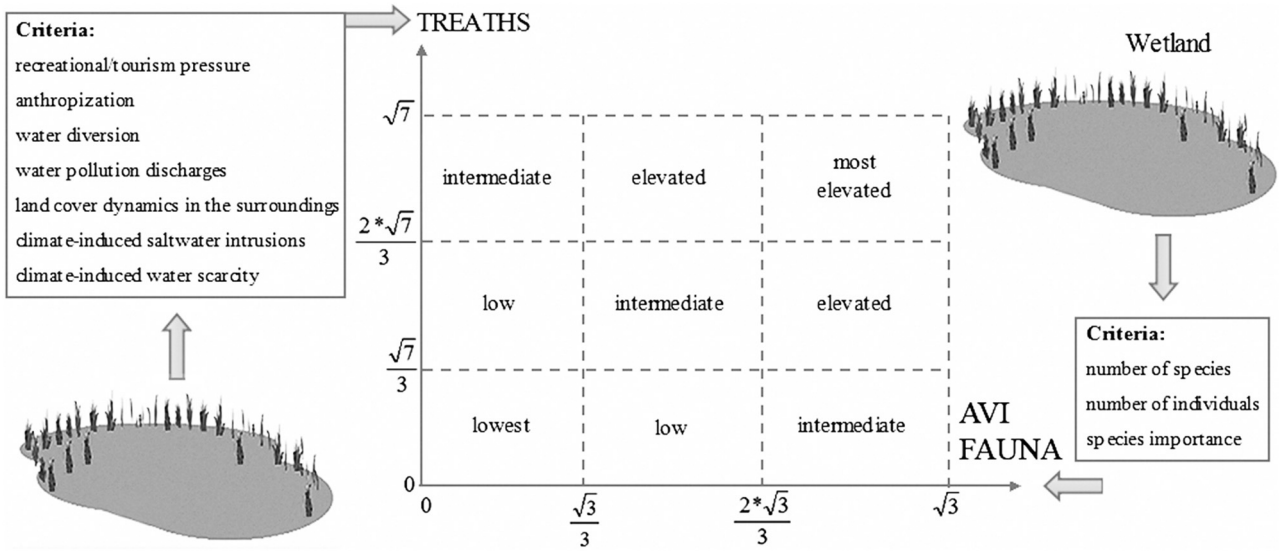

Fig. 2. The methodological framework used for wetland assessment and prioritization in Sardinia and Sicily. For each wetland, seven criteria of current and future threats were combined into one composite index (THREATS; Y-axis), and three criteria of avian diversity were aggregated into the AVIFAUNA index (X-axis). We built the decision space in the form of a biplot between these two indices, whose ranges were split into three equi-intervals: low, intermediate and elevated. Each wetland received a score for each index, thus resulting in a distinct position of the decision space.

discharges from the surrounding areas in six wetlands (THR2 = 2; Cabras, Colostrai, Feraxi, Is Benas, S. Giusta, Tortoli). Water diversion for farming activities was active only in three wetlands (Colostrai, Feraxi, Tortoli). The occurrence of artifacts in the close surroundings resulted elevated at S. Caterina (THR4 = 3), and intermediate in other three wetlands (THR4 = 2; Cabras, Pilo, Tortoli).

Eleven wetlands experienced anthropization processes in the surroundings during 2006–2012 (Suppl. Fig. S6), with Tartanelle scoring

Table 3
Scores of the main Sardinian and Sicilian wetlands with regard to the employed assessment criteria. See Table 1 for the code associated to each criterion.

Region	Wetland	BIO1	BIO2	BIO3	THR1	THR2	THR3	THR4	THR5	THR6	THR7
Sardinia	Cabras	8.8	1.6	2.0	0	2	0	2	1.6	0	5.8
Sardinia	Calich	3.4	1.1	2.0	3	0	0	0	0.1	0	11.7
Sardinia	Casaraccio	2.2	0.6	2.1	1	0	0	0	1.2	0	3.8
Sardinia	Chia	37.0	3.1	4.4	2	0	0	0	0.0	0	100.0
Sardinia	Colostrai	22.8	2.3	3.0	0	2	3	0	0.0	0	6.0
Sardinia	Feraxi	1.9	0.9	7.4	1	2	2	0	0.0	0	2.1
Sardinia	is Benas	4.3	0.8	1.2	1	2	0	1	0.0	0	7.2
Sardinia	is Brebeis	35.7	4.3	2.0	1	0	0	0	0.0	0	10.6
Sardinia	la Maddalena	24.7	2.6	2.6	2	0	0	1	0.0	0	7.0
Sardinia	Molentargius	128.1	2.9	0.6	0	0	0	0	0.2	0	12.4
Sardinia	Notteri	6.9	0.8	1.1	2	0	0	0	0.8	0	11.7
Sardinia	Pilo	138.4	6.8	4.1	2	1	0	2	0.0	1	5.4
Sardinia	Platamona	8.2	1.8	1.4	1	0	0	1	0.0	0	14.0
Sardinia	Porto Botte	66.6	3.0	1.5	2	0	0	0	0.0	0	4.7
Sardinia	S. Caterina	23.3	3.0	2.1	0	0	0	3	0.1	0	6.1
Sardinia	S. Giovanni	177.3	6.1	2.2	1	0	0	0	4.2	1	2.6
Sardinia	S. Giusta	23.6	3.6	0.7	2	2	0	0	2.4	0	4.5
Sardinia	S. Teodoro	18.4	2.4	2.8	3	0	0	0	1.8	1	8.4
Sardinia	Sa Curcurica	1.3	0.4	0.0	2	1	0	0	0.0	0	14.0
Sardinia	Sa praia	3.3	1.8	4.9	0	0	0	0	0.0	0	1.9
Sardinia	Tartanelle	14.5	1.4	6.4	3	0	0	0	7.2	0	3.5
Sardinia	Tortoli	6.3	0.6	1.2	3	2	2	2	0.9	0	2.4
Sicily	Auruca	0.0	0.0	0.0	0	2	3	3	0.1	0	100.0
Sicily	Baronello	52.9	4.9	5.7	1	2	1	2	0.1	0	16.0
Sicily	Cuba	82.2	3.9	4.4	0	0	2	1	0.4	0	100.0
Sicily	Faro	66.5	4.7	0.2	3	2	2	3	0.0	0	0.2
Sicily	Ganzirri	55.3	5.0	1.9	3	2	2	3	0.0	0	0.8
Sicily	Gela	71.0	6.6	4.6	1	3	3	3	0.0	0	3.9
Sicily	Gornalunga	78.6	5.9	6.8	2	2	0	3	0.0	1	11.5
Sicily	Longarini	7.2	0.2	0.3	3	3	3	3	0.3	0	100.0
Sicily	Morghella	0.3	0.1	0.0	1	2	3	3	0.0	0	100.0
Sicily	Pantano Bruno	70.9	4.1	3.7	1	2	2	3	0.3	0	34.8
Sicily	Pantano Grande	75.7	3.3	3.2	3	0	0	0	0.0	1	79.9
Sicily	Pantano Piccolo	150.2	3.4	5.4	2	0	0	0	0.0	0	14.8
Sicily	Preola	102.9	6.5	9.9	1	0	0	2	0.4	0	2.7
Sicily	Roveto	396.2	7.4	6.1	1	2	1	1	5.0	0	27.8
Sicily	Tindari	6.7	1.8	2.3	3	0	0	0	16.3	1	1.9
Sicily	Tondi	32.9	3.4	3.6	0	0	0	1	0.9	0	0.8

the highest value (THR5 = 7.2%). Three wetlands (Pilo, S. Giovanni, S. Teodoro; Suppl. Fig. S7) resulted at risk of permanent saltwater intrusions by 2040. Chia (THR7 = 100%) was projected to be completely dry in summer by 2040.

The decision plane (Fig. 3) assigned elevated priority for interventions to two wetlands, i.e. Pilo (AVIFAUNA = 1.383, THREATS = 1.463) and S. Giovanni (AVIFAUNA = 1.376, THREATS = 1.207). The Pilo wetland resulted to host elevated levels of avian diversity, and several bird species important for conservation (like the purple heron *Ardea purpurea*, the western swamphen *Porphyrio porphyrio* and the kentish plover *Charadrius alexandrinus*). The threats to this wetland concern primarily the tourism pressure, the anthropization of the close surroundings and the risk of permanent saltwater intrusions by 2040. The S. Giovanni wetland resulted to host elevated levels of avian diversity as well, and several bird species important for conservation (purple heron *Ardea purpurea*, greater flamingo *Phoenicopterus roseus*, little tern *Sternula albifrons*). The threats to this wetland concern primarily the land dynamics in the surroundings, and the risk of permanent saltwater intrusions by 2040. During 2006–2012, 124 ha of natural and semi-natural areas (4.23% of the 2-km buffer) shifted to arable land and permanent crops, thus suggesting similar dynamics in the next future with increased water diversions and discharges due to farming activities.

Intermediate priority resulted for three wetlands (Chia, Feraxi, Tartanelle). The Chia wetland is threatened by tourism pressure and water shortage in summer by 2040. During our field surveys, the average water depth resulted very low (1.6 cm ± 0.9 S.D., $n = 6$), and only in September it resulted 5.9 cm (±1.8 S.D., $n = 2$). The Feraxi

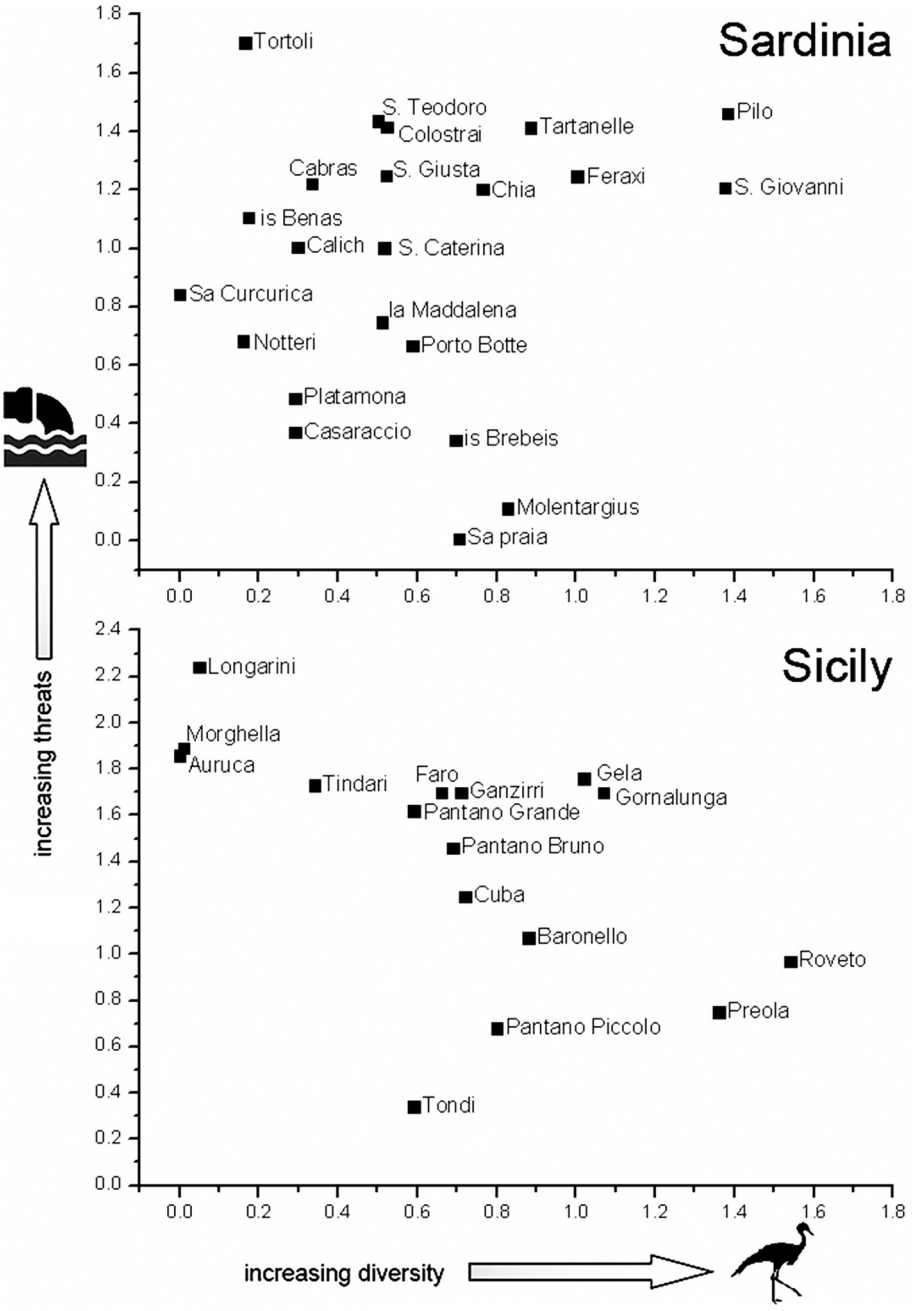

Fig. 3. Prioritization of the Sardinian (top) and Sicilian (bottom) wetlands. The two biplots show the composite indices of avian diversity (3 criteria) on the X-axis and threats (7 criteria) on the Y-axis. Wetlands received a score for each index, thus resulting in distinct positions in the decision space.

wetland was assigned the highest score (i.e. 7.4) of BIO3 in Sardinia. It resulted at risk due to water pollution discharges and water diversion. The Tartanelle wetland is threatened by tourism pressure and land dynamics in the surroundings. During 2006–2012, 134 ha of natural and semi-natural areas (7.19% of the 2-km buffer) changed to arable land and permanent crops (130 ha) and developed areas (4 ha), thus suggesting similar dynamics in the next future.

Low priority was assigned to twelve wetlands, whereas five wetlands (Casaraccio, Notteri, La Maddalena, Platamona, Sa Curcucica) scored low values on both indices, therefore resulting at lowest priority.

3.2. Sicily

Roveto (BIO1 = 396.2, BIO2 = 7.4; Table 3; Suppl. Fig. S8) scored the highest values for species diversity and abundance, whereas Preola (BIO3 = 9.9) had the highest score for the importance of conservation of the sampled species. Auruca (BIO1 = 0, BIO2 = 0, BIO3 = 0) scored the lowest values for all the criteria of avian diversity.

Tourism pressure (Suppl. Fig. S9) was elevated in five wetlands out of 22 (THR1 = 3; Faro, Ganzirri, Longarini, Pantano Grande, Tindari), and evident in further two (THR1 = 2; Gornalunga, Pantano Piccolo). We detected elevated pollution discharges from the surroundings in two wetlands (THR2 = 3; Gela, Longarini), and intermediate discharges in other 8 cases (THR2 = 2). Water diversion for farming activities was elevated in four wetlands (THR3 = 3; Auruca, Gela, Longarini, Morghella), and intermediate in other four (THR3 = 2; Cuba, Faro, Ganzirri, Pantano Bruno). The occurrence of artifacts in the close surroundings resulted elevated for eight wetlands (THR4 = 3), and intermediate for further two (THR4 = 2; Baronello, Preola).

Nine wetlands experienced anthropization processes in the surroundings during 2006–2012 (Suppl. Fig. S10), with Tindari scoring the highest value (THR5 = 16.3%). Three wetlands (Gornalunga, Pantano Grande, Tindari) resulted at risk of permanent saltwater intrusions by 2040 (Suppl. Fig. S11). Four wetlands were projected to be completely dry in summer by 2040 (THR7 = 100%; Auruca, Cuba, Longarini, Morghella).

The decision plane (Fig. 3) assigned elevated priority for interventions to just one wetland, i.e. Roveto (AVIFAUNA = 1.540, THREATS = 0.974). This wetland resulted to host elevated levels of avian diversity, and several bird species important for conservation (pied avocet *Recurvirostra avosetta*, little bittern *Ixobrychus minutus*, ferruginous duck *Aythya nyroca*). The threats to this wetland resulted manifold, but water pollution discharges, land dynamics in the surroundings and water scarcity in summer by 2040 resulted critical. During 2006–2012, 124 ha of natural and semi-natural areas (5.04% of the 2-km buffer) changed to arable land and permanent crops, therefore suggesting similar dynamics in the next future. During field surveys, the average water depth resulted adequate for waterbirds (14.8 cm ± 4.0 S.D., $n = 6$), but at the end of August 2016 it was only 4.6 cm, and 5.4 cm at the beginning of September.

Intermediate priority resulted for eight wetlands (Baronello, Cuba, Faro, Ganzirri, Gela, Gornalunga, Pantano Bruno, Pantano Grande), whereas low priority was assigned to seven wetlands (Auruca, Longarini, Morghella, Pantano Piccolo, Preola, Tindari).

4. Discussion

The Sardinian wetlands resulted primarily interested by tourism pressure (seventeen wetlands out of 22). This result agrees with recent studies about the rapid increase of mass tourism in Sardinia (Hospers, 2003; Iorio and Wall, 2012). The ongoing climate change is expected to impact four wetlands by 2040, one due to water shortage in summer and three due to permanent saltwater intrusions. The Sicilian wetlands resulted primarily under threat due to the anthropization of the close surroundings (13 wetlands out of 16), often due to the presence of greenhouses. This is in line with recent studies about the rapid development of greenhouses in Sicily to further increase the production of oranges, tangerines, wine and lemons (Riguccio et al., 2015; Riguccio et al., 2016). In Sicily, up to 40% of water for farming is taken outside the agricultural areas from the neighboring wetlands (ISTAT, 2014), easily resulting in water scarcity and degradation. The ongoing climate change is expected to further exacerbate this risk, in fact four wetlands resulted at risk of complete drainage in summer by 2040 when they should instead act as important stopover sites along the most important flyways between Europe and Africa, and other three wetlands resulted at risk of permanent saltwater intrusions.

4.1. Priority interventions

In Sardinia, two wetlands resulted at elevated priority for interventions. In the Pilo wetland, urgent interventions are required for the restriction of tourism activities (through the prohibition of: free camping, hunting and fishing activities, wildlife reintroduction for hunting purposes, sound and light emissions within at least 100 m from the wetland, the use of motor vehicles outside roads, and other potentially impacting activities) and anthropization processes (through the prohibition of new roads, buildings, quarries, landfills and other artifacts). Besides, the prevention of future saltwater intrusions (through the construction of artificial dune cordons at least 10 cm high) is required because the Pilo wetlands is very close to the coastline and has no natural/artificial barriers (Suppl. Table S8). In the S. Giovanni wetland, priority interventions concern the prohibition of a) water diversions and discharges, b) use of pesticides and herbicides, and the promotion of biological agriculture in the farm areas surrounding this wetland. As for the Pilo wetland, the prevention of future saltwater intrusions through the construction of artificial dune cordons is required (Suppl. Table S8).

Three wetlands (Chia, Feraxi, Tartanelle) resulted at intermediate priority for interventions. In the Chia wetland, besides the restriction of tourism activities, the prohibition of water diversions in the extra-summer period is required, so as to possibly increase the water volume in summer (Suppl. Fig. S12). Suitable conservation measures for the Feraxi wetland concern the restriction of water diversions and pollution discharges. In the Tartanelle wetland, fit conservation measures require the restriction of a) tourism activities, and b) water diversions and discharges. The remaining Sardinian wetlands scored low or lowest priority for interventions.

In Sicily, only the Roveto wetland resulted at elevated priority for interventions. Priority interventions in this wetland concern the prohibition of a) water pollution discharges and b) further agricultural expansion in the close surroundings, and the restriction of water diversion in summer so as to increase the water volume available at the end of August and the beginning of September.

Eight wetlands resulted at intermediate priority. Interventions for the mitigation, compensation and/or prevention of current threats resulted suitable at Baronello (water pollution and anthropization of the close surroundings; Suppl. Fig. S13), Cuba (water diversion), Faro and Ganzirri (all the current threats), Gornalunga (all the current threats but water diversion), Pantano Bruno (all the current threats but tourism pressure) and Pantano Grande (tourism pressure). The ongoing climate change is expected to threaten the Cuba wetland (water shortage by 2040), Gornalunga (saltwater intrusions by 2040; Suppl. Table S9) and Pantano Grande (water shortage and saltwater intrusions by 2040; Suppl. Fig. S14). The mitigation of the climate change impacts should be primarily focused on these three wetlands. The remaining Sicilian wetlands scored low or lowest priority for interventions.

4.2. Methodological issues

Wetland size could influence biodiversity criteria BIO1, BIO2 and BIO3 (Froneman et al., 2001; Paracuellos and Telleria, 2004). Because waterbirds have different preferences with respect to habitat configuration, the larger wetlands, which are more likely than smaller wetlands

to have elevated habitat heterogeneity, can support a greater diversity of waterbirds than the smaller ones (Colwell and Taft, 2000; Paracuellos, 2006). Avian diversity in a wetland can also be affected by wetlands nearby (Kelly et al., 2008). However, we avoided using wetland size and connectivity as decision criteria because BIO1, BIO2 and BIO3 were already function of these variables, therefore their inclusion would have introduced multicollinearity and redundancy into our decision model. In addition, BIO1, BIO2 and BIO3 are direct (proximal) estimators of species diversity, while wetland size and connectivity are only distal.

We assigned a score of importance for avian conservation on the basis of SPEC and Global Red List values, and avoided using further weights from regional or national lists. The rationale behind this choice was that almost 90% of the sampled avifauna was represented by migratory species (Suppl. Table 3), whose conservation interest was thus mainly at European and global level.

Our assessment of the current threats was semi-quantitative (Voogd, 1983). An alternative approach based on precise and quantitative assessment (e.g. number of tourists active in the surroundings of each wetland, water volume used for farming etc.) was outside the reach of our study. However wetland prioritization is a comparative, not absolute, framework thus, although quantitative values are always preferable, semi-quantitative scores can perform well for this purpose (Zeleny, 1982). Besides, field surveys in each region were carried out by the same group of experts, thus ensuring a tenable comparative assessment of the current threats.

The two criteria THR1 (recreational/tourism pressure) and THR4 (anthropization) could potentially be positively correlated and redundant. However they resulted negatively, but not significantly, correlated in both regions (Suppl. Table S10). In fact, during field surveys we observed that most tourists reached wetland areas using motor vehicles or also by walking, and did not strictly need to reside in a tourist area close to the wetland. Thus THR1 and THR4 were conceptually independent, and resulted statistically uncorrelated (Suppl. Table S10).

The projection of future threats required us to use recent land dynamics as predictors of the future processes of anthropization in the surroundings of the studied wetlands. We are aware that the persistence in the kind of land changes in a certain area is not automatic, however recent land changes can reasonably outline the direction in land dynamics at least on brief and mid-term, in fact many studies have been successful in predicting future land dynamics purely on the basis of recent land changes (Mas et al., 2014). The risk of water scarcity in summer by 2040 was computed on the basis of the extreme RCP8.5 climate scenario. Our choice was precautionary, in that if wetlands are not at risk of water shortage, not even in the extreme climate scenario, then there's a reliable reason to avoid any kind of preventive interventions aimed to increase water availability in summer. The Thornthwaite equation is a widely used method for estimating potential evapotranspiration, and showed to perform well in studies of evaporation from wetlands (e.g., Rosenberry et al., 2004) where the potential evapotranspiration well approximates actual wetland evaporation (Lott and Hunt, 2001). Besides, it offered the remarkable advantage of just requiring mean monthly air temperature (calculated from latitude and elevation a.s.l. of the wetland centroid) and mean daily daylight hours for each month (calculated from latitude of the wetland centroid) as input data.

5. Conclusions

Our study emphasized that the largest wetlands in Sardinia and Sicily experience different levels of human and climate threats, leading to different impacts on wetland integrity, the associated avifauna, and the functional role of stopover sites along important flyways. Accordingly, the 38 main wetlands in these two regions require tailor-made conservation actions, going from the mitigation of tourism pressure to the prevention of saltwater intrusions by 2040. Because all the wetlands considered in this study are Natura 2000 sites as well, these threats should be considered relevant in their conservation measures and management plans. Besides, clear priorities for interventions emerged in both regions.

Our study increases the practicality of pro-active measures for preserving the main wetlands, and the associated avian diversity, under human and climate threats in Sardinia and Sicily. In fact, considering the rapid general decline in the integrity of the studied wetlands, which put at risk their role as habitat for waterbirds, it is important to act swiftly to put in place conservation measures, starting from the sites that are at elevated risk. Our study, by circumscribing the number of wetlands for which interventions resulted urgent, provides researchers and conservation managers a tool to thoroughly limit their efforts to a restricted number of suitable sites and interventions, thus increasing the feasibility of sound conservation strategies for the main stopover sites along the Mediterranean flyways.

CRediT authorship contribution statement

AF, MG and CC conceived the paper. MG carried out the field surveys. AF performed the GIS and modelling work. All authors wrote, edited and reviewed the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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