

Knowledge gaps and challenges for conservation of Mediterranean wetlands: Evidence from a comprehensive inventory and literature analysis for Sardinia

Mauro Fois  | Alba Cuenca-Lombrana  | Gianluigi Bacchetta 

Centro Conservazione Biodiversità,
Dipartimento di Scienze della Vita e
dell'Ambiente, Università degli Studi di
Cagliari, Cagliari, Italy

Correspondence

Alba Cuenca-Lombrana, Centro Conservazione
Biodiversità, Dipartimento di Scienze della Vita
e dell'Ambiente, Università degli Studi di
Cagliari, Viale S. Ignazio da Laconi, 11-13,
Cagliari 09123, Italy.

Email: albacuenca@gmail.com;
alba.cuenca@unica.it

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Abstract

1. Wetlands are some of the most important ecosystems on Earth. They play a key role in mitigating climate change-related events and filtering polluted water, and provide habitats for a wide range of species. Despite their importance, and numerous regulations that support their conservation, wetlands continue to be destroyed. Recent reports have indicated a progressive decline in ecological character of remaining wetlands.
2. This research reviews and extends the present status of wetland knowledge in Sardinia, the second largest Mediterranean island. For the first time, Sardinian wetlands were comprehensively mapped using satellite images and field validation. Impacts were also assessed. Trends in literature published about Sardinian wetlands since 1900 were then analysed, mainly according to the location(s) and topic(s) studied.
3. In total, 2,501 Sardinian wetland sites were identified. The most common impacts observed in the field were vegetative degradation and water pollution. Of these wetlands, 2,274 have never been the subject of a research paper. Despite recent increases in publication rates, there was a lack of even basic knowledge about many wetlands, especially smaller ones. Larger wetlands have been studied from a range of viewpoints.
4. In the light of these results, suggestions for improved awareness, effective management and conservation of Mediterranean wetlands were established. Future work should be directed to filling gaps in basic information, and to improvements in research and conservation, which might include multidisciplinary approaches in support of more comprehensive conservation management plans.

KEYWORDS

conservation planning and policies, Mediterranean Basin, multidisciplinary approach, systematic map, wetland inventories, wetland research

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1 | INTRODUCTION

The Mediterranean Basin is one of the richest biodiversity hotspots, and the subject of several biodiversity assessments, management studies, and conservation actions (Cuttelod et al., 2009). Among Mediterranean ecosystems, wetlands are critical for biodiversity. Although they occupy only 2–3% of the terrestrial surface, they support more than 30% of vertebrate species, as well as impressive numbers of microbes, plants, insects, and other species. Such high species richness is the result of the transitional nature of wetlands, meaning that they can support both terrestrial and aquatic species, from adjacent environments or further afield, at least transiently. Mediterranean wetlands are also important for people. They offer nature-based solutions to problems such as climate change, provide ecosystem services that contribute to human well-being, and support many economic activities (Geijzenborffer et al., 2019a). They are hotspots of ecosystem productivity and key regulators of coastal erosion and of biogeochemical cycles, including flows of water and associated nutrients, pollutants, and sediments (García-García et al., 2009).

Although the establishment of organizations — such as the International Union for Conservation of Nature in 1948, the Ramsar Convention in 1971 and the Convention on Biological Diversity in 1992 — has provided impetus for wetland conservation and management, there is an increasing need to conserve Mediterranean wetlands. Since 1970, the surface area of natural Mediterranean wetlands has decreased by 48% on average. This exceeds the global average of 35%. Meanwhile, only 44% of Mediterranean Ramsar sites have a management plan in place (Geijzenborffer et al., 2019a).

Mediterranean wetlands are threatened by anthropogenic factors such as construction of infrastructure and urban areas, conversion to agricultural land, irrigation, pollution, eutrophication, sediment loading, and hydrological alterations. Wetlands may be directly altered by these activities, or indirectly affected by activities in their catchments. In addition, Mediterranean wetlands are being affected, and will continue to be affected, by large-scale environmental changes such as warming temperatures, increased aridity and soil salinity, sea level rise and biological invasions (Pascual-Aguilar et al., 2015; Bolpagni, 2021).

Inventories, comprehensively describing the location, size, and other characteristics of wetlands in a defined area, are crucial for informed and wise decisions regarding wetland conservation (Bolpagni, 2020). However, many areas lack detailed inventories or directories and instead rely on information about wetlands generated as a by-product of other activities, such as bird surveys or land use cover appraisals (Finlayson et al., 1999). Existing inventories, both coarse and high resolutions and global or regional scales, are often based on satellite imagery and lacked consistent field validation. This has led to the neglect of several aspects, such as characterization of biological diversity and disturbances, and the detection of specific habitat types.

In the Mediterranean Basin, since the establishment of the Mediterranean Wetland Initiative (MedWet, <https://medwet.org/>) in

1991, a standardized method has been defined to provide knowledge about wetlands to policy makers, non-governmental organizations, and wetland site managers (Costa et al., 1996; Geijzenborffer et al., 2019b). Despite the compilation of much information on wetlands at global, Mediterranean, and national scales (Perennou et al., 2012; Geijzenborffer et al., 2019a), further improvements are needed. For instance, the interconnection of databases is irregular and, to include functional diversity, more data are necessary to bridge the remaining gaps and methodological variability (Cornwell et al., 2019). Moreover, national programmes to monitor trends and to improve the network of protected wetlands by including certain under-represented wetland types, such as temporary and small wetlands, are required in all countries, even where national inventories exist (Finlayson et al., 1999; Perennou et al., 2012).

This research is focused on wetlands of the second largest Mediterranean island (Sardinia, Italy). It is home to around 1.6 million people (approximately 68 inhabitants km⁻²) and attracts approximately three million tourists annually (Fois, Fenu & Bacchetta, 2019). Sardinia is of special biological interest because of its central geographical position in the western Mediterranean Sea. It hosts a great variety and number of wetland types and species related to both the African and European continents (Vogiatzakis, Mannion & Sarris, 2016). Accordingly, eight Ramsar sites and numerous protected areas have been specifically designated for the protection of wetlands in Sardinia. Despite this, efforts are needed to address knowledge, policy, and conservation gaps (Bagella, Caria & Filigheddu, 2013). A comprehensive inventory of Sardinian wetlands would certainly help to guide monitoring and conservation plans, for example by ensuring that temporary and small wetlands are not overlooked. Other Mediterranean islands face similar challenges, meaning that Sardinia can be used as an illustrative case.

Existing policies and laws applied to Sardinian wetlands are derived mainly from international commitments and the obligations of the European Union (EU). These include: the Birds and Habitats directives (Council of the European Communities, 1992, 2010) and their derivative Natura 2000 network; the European Water Framework Directive (Council of the European Communities, 2000a), which embodies many existing directives with implications for wetlands; the European Landscape Convention (Council of the European Communities, 2000b), which promotes the protection, management and planning of landscapes, and the Ramsar Convention, which identifies wetlands of international importance. More recently, investments in wetland conservation and sustainable use also contribute directly to the fulfilment of Italy's commitments under the Paris Agreement, in order to combat climate change and adapt to its effects (UNFCCC, 2015).

In line with the aforementioned EU principles, such as the European Landscape Convention, Italy delegates each region through the Legislative Decree n. 42/2004 to develop its own landscape plan (Piano Paesaggistico Regionale) that in turn provides guidelines for designing municipal master plans (Piano Urbanistico Comunale). This framework is partially in synergy with the application of the Water Framework Directive where inter-jurisdictional strategic plans,

including groups of neighbouring municipalities, are also requested. The Autonomous Region of Sardinia approved its Piano Paesaggistico Regionale in 2006 and initiated the process for the definition of its Strategic Environmental Assessment (SEA) through two laws passed in 2008 and 2012 (De Montis et al., 2014). In addition, the obligation of metropolitan cities, that de facto partially replaced the province level, represented an opportunity to develop comprehensive SEAs at the drainage basin scale. Examples are the integrated management models promoted for the Ramsar sites of the Gulfs of Oristano and Cagliari (Palumbo et al., 2020; Ivčević et al., 2021).

This work presents an inventory of Sardinian wetlands and an analysis of published research related to them. The main aims of this study were to: (i) improve the current knowledge about the rich array of wetlands in Sardinia; (ii) investigate scientific research relating to Sardinian wetlands in order to identify temporal trends, knowledge gaps and knowledge clusters (including links between them); (iii) identify challenges to the conservation of Sardinian wetlands and to discuss how such challenges might extend across the Mediterranean. This information will guide future management of, and research about, Mediterranean wetlands.

2 | METHODS

2.1 | The starting point to delve into Sardinian wetlands: the inventory

The Ramsar Convention defines wetlands as “areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres” (Ramsar Convention Secretariat, 2013). The current project followed this definition but excluded: (i) streams, rivers, and other running water; and (ii) wetlands with a surface area less than 0.1 ha.

A preliminary inventory was created in Quantum GIS version 1.7.4 (QGIS, 2014) by identifying and digitizing all wetlands visible on high-resolution satellite images from Google Earth (<http://www.google.com/earth>; Costa et al., 1996; Perennou et al., 2018). Where there was uncertainty in the area of a wetland, the largest potential polygon was defined according to seasonal fluctuations in inundation and vegetation cover that were observed in the available Google Earth imagery time series. This approach avoids underestimation of flooded areas that might be only temporarily inundated or masked by dense aquatic vegetation (Perennou et al., 2018). Each wetland was then classified according to the typology in the pan-Mediterranean wetland inventory module, a hierarchical classification of the common types of Mediterranean wetlands within three mutually exclusive macro-categories: coastal, inland, and artificial (Tomàs-Vives, 2008).

The preliminary inventory was validated through field observations (400 wetlands; 16% of inventory) and further desktop studies (2,101 wetlands; 84% of inventory). Field observations were carried out mainly in spring, when physical and biological indicators

were most likely to be present. For small wetlands (ca. <5 ha), entire perimeters were delineated using a hand-held GPS receptor (Garmin e-Trex 20, Schaffhausen, SW). For larger wetlands, field validation focused on uncertain boundaries identified in the GIS. Desktop analysis involved interpretation of aerial and ground-based photographs and comparisons with cartographic products in the database of the Autonomous Region of Sardinia (<http://www.sardegnageoportale.it>). The presence or absence of impacts was also recorded for each wetland visited, following the MedWet scheme (Tomàs-Vives, 2008). The impacts were classified as follows: loss of aesthetic value(s), faunal changes, habitat degradation, decrease in wetland benefits, pollution, soil/land impacts, vegetative degradation, hydrological impacts.

2.2 | Literature analysis

Peer-reviewed research related to Sardinian wetlands published between January 1900 and December 2019 was reviewed (searched January 2020 in Web of Science, Scopus, and Google Scholar). The review of papers involved searches in English and Italian. It must be acknowledged that the search may have missed papers at scales larger than Sardinia (e.g. Italy, Europe, entire Mediterranean, or global) with relevant information on Sardinian wetlands.

From 8,530 initial results, publications that were not journal articles (e.g. books, book chapters, conference abstracts) and duplicates were removed, leaving 1,340 results. Subsequent screening of titles, abstracts, and full texts yielded a final list of 344 papers that carried out empirical research on one or more Sardinian wetlands (see Table S1).

All wetland study sites from each paper were extracted and georeferenced in QGIS and overlaid on wetland inventory and protection status layers. Log-linear models (Agresti, 2003) were fitted in R statistical software (version 3.6.1) (R Core Team, 2019) to test whether the following wetland attributes determined the number of papers per wetland: wetland type (16 categories), natural (yes/no), coastal (yes/no), protection (yes/no). In addition, all 344 relevant papers were categorized using 11 topic areas that are listed in Table 1. The maximum number of topics in a single paper was three. Lastly, a network analysis was conducted, using the software Gephi 0.9.2 (Bastian, Heymann & Jacomy, 2009), to analyse links between the research topics in each paper.

3 | RESULTS

3.1 | Wetland inventory

In total, 2,501 wetlands were found in Sardinia, covering a surface area of 494.2 km² (ca. 2% of the Sardinian territory). The full dataset is available online, in the framework of the Mediterranean Island Wetland project (<https://italiaiswet.it>).

The wetlands are highly variable in size, ranging from a minimum of 0.1 ha to the 6,566 ha of the Santa Gilla Lagoon. Artificial wetlands

TABLE 1 Description of the research topics to which papers were allocated, and some examples of papers included

Research topic	Description	Examples
History & Archaeology	Exploitation of wetland resources in ancient times, archaeological excavations, and analysis of human interaction with local landscapes	Marine and inland water resources in history (Carenti, 2013); recent industrialization (King, 1977)
Hydrology	Properties, distribution, and circulation of water	Tidal, seiche, and wind dynamics (Niedda & Greppi, 2007)
Geology & Palaeontology	Past geological periods: fossil remains, sedimentological aspects, and geological characterization	Structural and sedimentary evolution and sedimentological impacts (Di Gregorio & Massoli-Novelli, 1992); palaeobotany (Cleal et al., 2017)
Flora	Vascular plants, bryophytes, and phytoplankton. Includes investigations of communities, ecology, population biology, reproduction, biotic interactions, taxonomy, phylogeny, and geographical distribution	Checklists, new species and records (Bacchetta, Brullo & Salmeri, 2010); vegetation descriptions, floristic inventories (Bagella & Caria, 2012)
Fauna	Animals: macro or micro, vertebrates and invertebrates. Includes investigations of communities, ecology, population biology, reproduction, biotic interactions, taxonomy, phylogeny, and geographical distribution	Ecology, new species descriptions and records (Hardersen & Leo, 2011; Cadeddu, Giacoma & Castellano, 2012)
Conservation assessment & Management	Conservation management or conservation planning; ecosystem and species conservation status; the complexity of environmental problems, with a view to informing conservation solutions or management	Wetland management and restoration plans (Magni et al., 2008); efficiency of Natura 2000 network (Bagella, Caria & Filigheddu, 2013)
Pollution	Water quality; concentration of pollutants, chemicals and/or organic matter	Effect of waste water on trophic status (Lugliè et al., 2001); analysis of mining-derived pollutants (Cidu et al., 1997)
Diseases	Analysing risks related to human health; food-borne diseases and infections; organisms such as bacteria, parasites, viruses; biotoxins	Malaria (Marchi & Munstermann, 1987); infection and viruses from wild birds (Kelvin et al., 2012)
Sustainable economy & Tourism	Natural resource management with a perspective of economic exploitation, but also considering maintenance of the functionality of natural systems. New economic models focusing on combined economic–environmental concerns in accordance with sustainable development policies	Green infrastructure and ecological corridors (Cannas et al., 2018); development of low impact aquaculture (Chessa et al., 2005); sustainable water policies (Corsale, 2011); environment and tourism in fragile territories (Lai & Sistu, 2015)
Dissemination policies	Communication, education and awareness-raising activities, including how to enhance exchange of knowledge between the local population and stakeholders	Overview of Italian Long-Term Ecosystem Research network (LTER-Italy) (Pugnetti et al., 2013); empowering local communities through collective grassroots actions (Ruiu & Ragnedda, 2017)
Economic production	Utilization of wetland resources for economic activities such as aquaculture, fishing and salt production; analysing the monetary value of wetland resources	Floating upwelling system for breeding of <i>Venerupis decussata</i> juveniles (Chessa et al., 2013), eel fishing management (Rossi & Cannas, 1984)

are more numerous (1,795) than natural wetlands (706; Table 2). However, natural wetlands, especially those in coastal areas, are generally larger than the artificial ones, with a total surface area of 365.6 km² (compared with 128.6 km² for artificial wetlands). Natural

wetlands are spread across the whole island, with approximately equal coastal (347) and inland (359) numbers. However, most (93.5%) of the wetland area is coastal. Seasonal freshwater ponds are the most common type of natural wetlands (193; 27.3% of natural wetlands),

TABLE 2 Summary of the number and surface area of inventoried Sardinian wetlands, grouped according to macro-category and type

Wetland typology	n	N referenced (%)	Area (km ²)	Area studied (%)	Main impact
Natural: Coastal					
Wetland system	22	15 (68.2%)	213.4	210.8 (98.8%)	P
Estuary	56	18 (31.6%)	28.2	25.8 (91.5%)	V
Permanent pond	66	25 (37.9%)	30.8	24.0 (77.9%)	H
Temporary brackish pond/marsh	112	16 (14.3%)	6.6	0.8 (12.1%)	P
Marsh/swamp	47	1 (2.1%)	2.6	1.1 (42.3%)	P
Lagoon	15	9 (60.0%)	60.0	58.9 (98.2%)	W
Temporary saltwater pond/marsh	29	4 (13.8%)	1.6	1.1 (68.8%)	P
total	347	88 (25.4%)	343.2	322.5 (94.0%)	V
Natural: Inland					
Temporary freshwater pool	193	28 (14.5%)	4.5	1.8 (40.0%)	V, H
Temporary brackish pool	10	4 (40.0%)	2.6	1.8 (69.2%)	H
Marsh/swamp	129	11 (8.5%)	7.3	1.6 (21.9%)	H
Permanent freshwater pond/lake	20	2 (10.0%)	0.5	0.1 (20.0%)	S
Permanent brackish/saltwater pond	7	6 (85.7%)	7.5	7.5 (99.9%)	A, L
total	359	51 (14.2%)	22.4	12.8 (57.1%)	H
Artificial					
Artificial pool	1297	29 (2.2%)	8.7	0.6 (5.7%)	V
Mining pool	178	9 (5.1%)	3.7	0.6 (16.2%)	S
Dam lake/river barrier	160	50 (31.3%)	115.0	106.8 (92.9%)	W
Concrete/membrane reservoir	160	0 (0%)	1.2	0 (0%)	A, V
total	1795	88 (4.9%)	128.6	107.9 (83.9%)	V
TOTAL	2501	227 (9.1%)	494.2	443.2 (89.7%)	

Note: Left-hand columns give the total number and area of wetlands in the inventory; right-hand columns give the number and area of wetlands with studies in the literature analysis. Main impacts are pollution (P), habitat degradation (H), decrease in wetland benefits (L), hydrological impacts (W), loss of aesthetic value (A), faunal changes (F), soil/land impacts (S), and vegetative degradation (V).

although a small number (22) of coastal wetland systems contribute most of the surface area (62.8% of natural wetland surface). Most artificial wetlands are artificial pools (1,297; 72.3%) but these cover only 8.7 km² (6.8% of artificial wetland surface), while the 160 riverine reservoirs comprise 89.4% of the total artificial wetland surface.

In total, 955 impacts were recorded for the 400 wetlands monitored; these were mainly related to vegetative degradation (185 wetlands), pollution (155), and habitat degradation (113), followed by a decrease in wetland benefits (93), loss of aesthetic values (91), faunal changes (82), and soil/land impacts (54). Among macro-categories, vegetative degradation was the most commonly recorded impact for coastal (81) and artificial (70) wetlands, and habitat degradation for inland wetlands (15; Table 2).

3.2 | Spatial and temporal trends of publications

Of the 2,501 identified wetlands, 227 (9.1%) are referenced in at least one of the 344 reviewed papers (Table 2). Studies have generally been concentrated in larger sites: the proportion of wetland area studied (89.7%) is far higher than the proportion of individual sites that have been studied (9.1%). This is also true for all wetland types other than

temporary brackish ponds and marshes. Based on counts of papers alone (not their content), coastal natural wetlands were the most completely investigated, followed by inland natural wetlands in terms of number and artificial ones in terms of area. Among the 16 types, permanent wetlands were the most investigated (33% by number; 74% by area). This included coastal lagoons, estuaries and wetland systems and the inland permanent ponds and lakes. Among artificial wetlands, dam lakes/river barriers were most investigated (31% by number; 93% by area), with little published about other types.

The log-linear model results showed significant effects of wetland type and protection status on study effort (proxied by number of papers; Figure 1). For wetland type, temporary pools were significantly ($P < 0.05$) under-represented in the literature. There was also under-representation of temporary brackish/saltwater pools, although this was poorly statistically significant ($P < 0.1$), and significant over-representation ($P < 0.001$) of both wetland systems and dam/river barriers. Regarding protection status, legally protected sites were over-represented in literature ($P < 0.001$).

There was a general increasing trend in publication rates, rising particularly rapidly over the past two decades. Several national and international conventions and legislation, such as the Habitats Directive, could have contributed to such a trend (Figure 2).

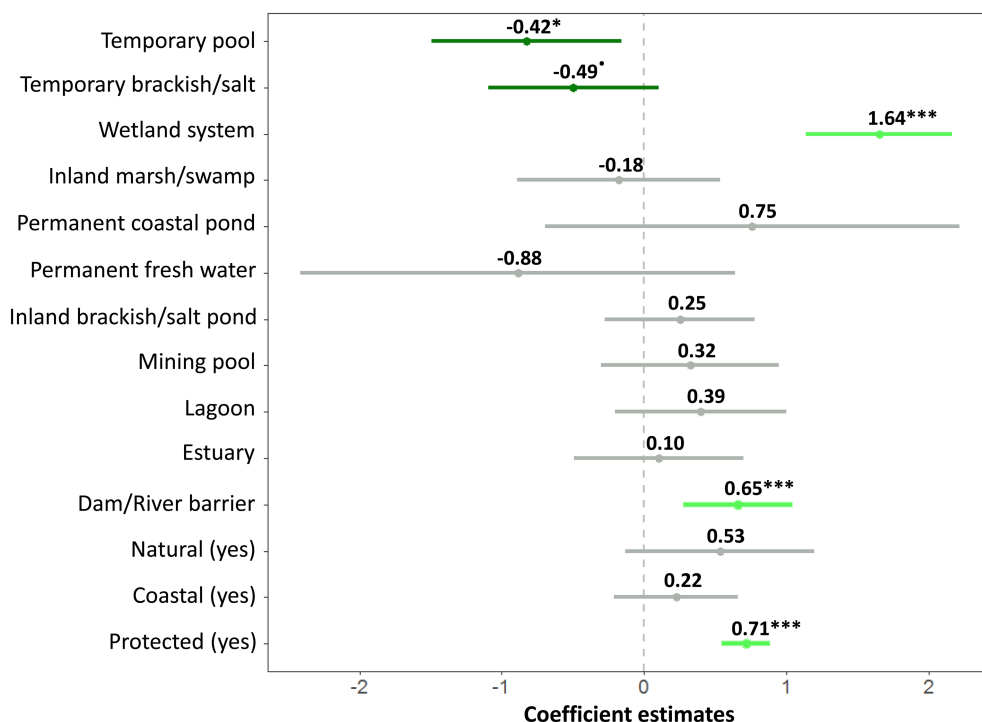


FIGURE 1 Coefficient plots (made by 'coefplot' function in the 'coefplot' R package, Lander, 2018). Dots depict coefficient estimates derived by the log-linear model, while the whiskers indicate the related standard error around each estimate. Asterisks ($P < 0.1$; *: $P < 0.05$; ***: $P < 0.001$) are for the positive (light green) and negative (dark green) significant estimates. Consult Table 2 for full names of wetland types

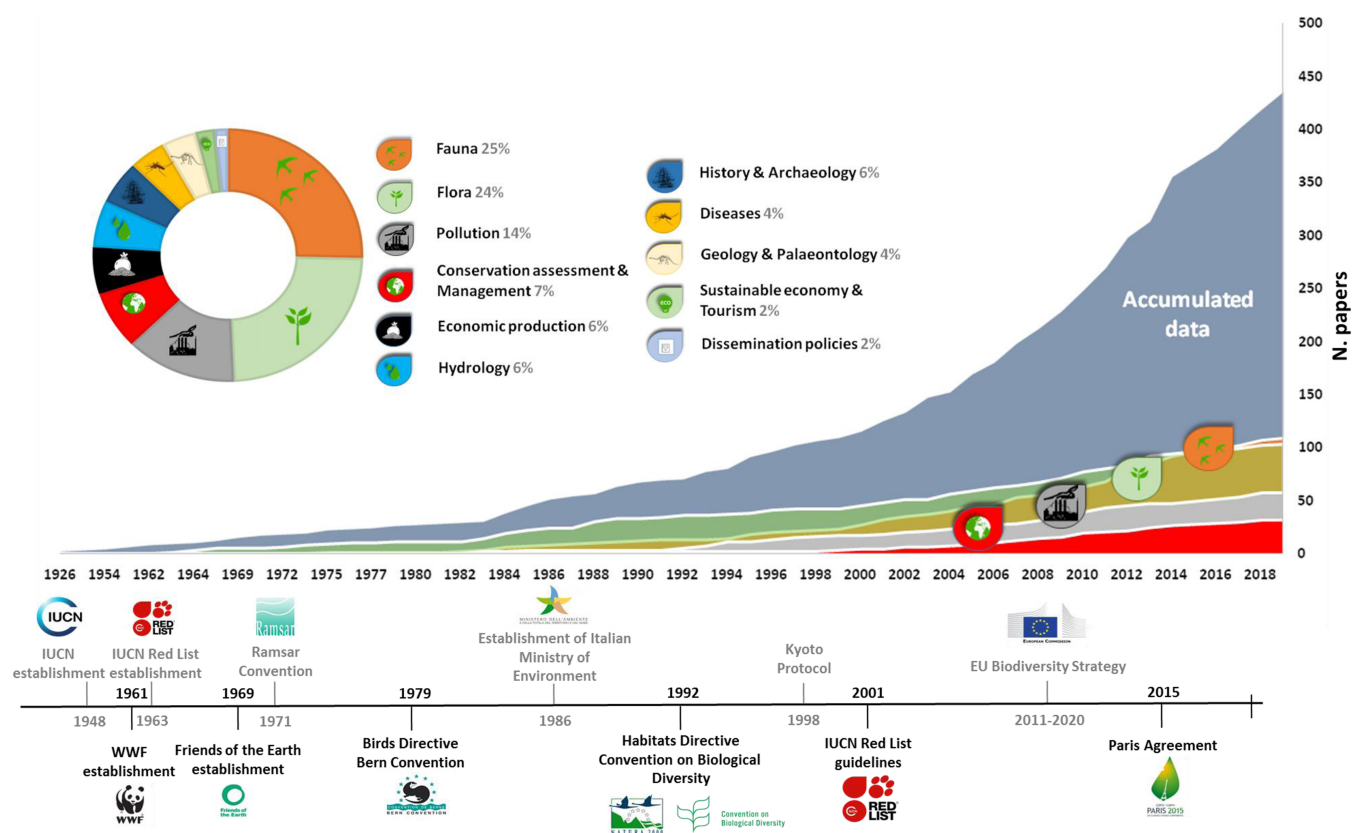


FIGURE 2 Trends in research on Sardinian wetlands. (a) Pie chart of papers by research topic; papers covering multiple topics were counted multiple times. (b) Temporal accumulation of papers, with the four main research topics highlighted (flora, fauna, pollution, and conservation assessment and management). The earliest paper found was published in 1926. National and international initiatives, laws, conventions, and the establishment of networks were chronologically reported below the accumulated trend. Icons used in this figure were downloaded from <https://pixabay.com/>

3.3 | Analysis by research topic

Among the 11 defined research topics (Table 1), more than half of the 344 research papers concerned flora and/or fauna (Figure 3). Pollution was another common research topic (58 papers), followed by conservation assessment and management (32) and economic production (27).

Most papers (264; 76%) dealt with only one research topic. Seventy-three papers (21%) were related to two research topics, and only nine papers (3%) addressed three research topics. This pattern varied among topics. For example, papers dealing with fauna were multi-topic (also addressing subjects such as pollution, economic production, diseases, and conservation assessment and management) significantly more often than papers dealing with flora (Figure 3). Five research topics were more often considered in a multi-topic than a single-topic approach, including conservation assessment and management (mostly with flora and fauna), economic production (with sustainable economy, conservation assessment and management, pollution and diseases), and geology and palaeontology (with hydrology, history and archaeology, and flora).

4 | DISCUSSION

4.1 | Wetland inventory, literature analysis, and conservation implications

The findings of this study have presented the most complete inventory to date of Sardinian wetlands, comprising 2,501 mapped

sites. The inventory was founded on analyses of satellite imagery, which offers great potential for such work because of its repeated, homogeneous coverage of large regions (Rebelo, Finlayson & Nagabhatla, 2009). The inventory represents a valuable tool for the scientific community, policy makers, and wetland managers. For instance, recognizing that 2,274 of the 2,501 Sardinian wetlands have never been investigated is a crucial starting point and offers an important baseline for continuing monitoring.

As expected, the most commonly studied wetlands were the largest. These offer the most potential study sites, but are also the most affected by a long history of human presence, reflecting both historical and archaeological interests and recent economic interests (King, 1977). For example, the largest Sardinian wetland, Santa Gilla Lagoon, is adjacent to the island's capital, Cagliari. Natural large coastal wetlands are the most protected for their high environmental value, but their conservation status is changing, especially owing to pollution problems and hydrological impacts related to past activities such as malaria eradication or agricultural expansion, or more recent impacts associated with human population growth (Marchi & Munstermann, 1987; Geijzenborffer et al., 2019a).

Conservation policies and management continue to be hampered by inadequate and/or obsolete scientific knowledge (Orlikowska et al., 2016). Even basic research was limited on small wetlands, temporary wetlands, and most artificial wetlands. For example, in Sardinia, other research on topics such as conservation assessment and management, diseases, and pollution, is largely absent in relation to small wetlands. However, these were recorded here and generally found as more widespread issues among all wetland types.

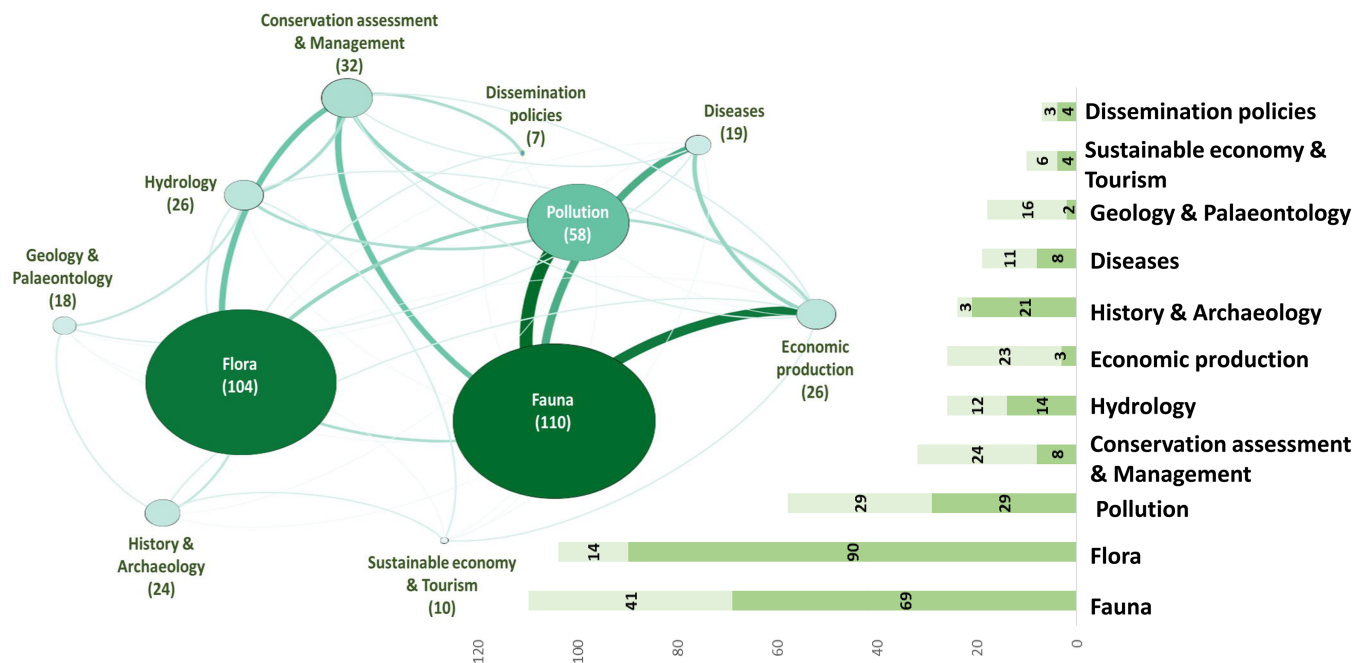


FIGURE 3 Network analysis of papers studying Sardinian wetlands by research topic. Dimensions and colour of circles and numbers indicate the number of papers dealing with each research topic. The width and colour of lines are related to the number of connections with other research topics. Histograms show the number of reviewed papers dealing with one research topic (dark green) or multiple research topics (light green)

Temporary ponds are recognized as a wetland type of international importance by the Ramsar Convention (Ramsar Resolution VIII.33). They are also included as a priority habitat for the EU under the auspices of the Habitats Directive (Council of the European Communities, 1992) because they are critical for biodiversity. Temporary ponds and other small wetlands are irreplaceable environments often containing distinct species, and are important stepping stones in ecological corridors and networks of conservation areas (Boix et al., 2012; Bagella et al., 2016). However, they are threatened by several human activities, mainly related to habitat fragmentation, vegetative degradation, and pollution. The high sensitivity of these environments is intrinsically the result of their limited extent, but also because they are often poorly identified and unappreciated, leaving them vulnerable even to unintentional destruction (Bagella, Caria & Filigheddu, 2013). To make significant progress on their conservation, improved basic information such as inventories is needed, but they should also be included as a specific water-body type under the European Water Framework Directive (Oertli et al., 2005; Bolpagni et al., 2019).

Alteration of flow regimes and sediment budgets were recorded in artificial wetlands, such as dam lakes. The degree of this impact is often directly correlated with the extent of the dam, which is often the cause of conflicts among the interested parties (Saulnier-Talbot & Lavoie, 2018). Increasing policy measures to secure or decommission dams (such as the Regional Law n. 12/2007 in Sardinia) might be an opportunity to reduce adverse impacts or, in some cases, increase their environmental value. In this sense, application of research knowledge in management and decision-making will be crucial to avoid ecosystem impacts, such as homogenization of the riverscape and colonization by alien species, identified as the main impacts in artificial pools and reservoirs.

4.2 | Literature analysis: spatial and temporal trends of publications

Since the 1920s, the number of papers published about Sardinian wetlands has constantly grown. Their flora and fauna have been studied since the beginning of the last century. Pollution research and conservation assessment and management emerged during the 1990s. Assuming a correlation between the number of publications and knowledge, understanding of Sardinian wetlands has increased over the 20th century, especially for flora, fauna, and pollution. Understanding has also increased for: (i) wetland ecosystem services, such as those related to economic production, hydrology, and human health; and (ii) archaeological aspects, justified by the presence of ancient settlements and activities.

This literature review has highlighted possible knowledge gaps: topics that have been rarely studied in the Sardinian context. First, Sardinian wetlands have been used by humans for thousands of years – for example as a water resource, for fishing–hunting–gathering, (proto-) agriculture (Carenti, 2013) – but surprisingly attitudes towards wetlands have not been more widely studied. The

sustainable use of wetlands will enhance their long-term conservation, avoiding conflicts between human needs and maintenance of ecological functions (Brock, 2009). Second, papers about sustainable economic development and tourism only appeared recently, after 2002. Research on this topic could significantly contribute to effective management of wetlands, supporting economic development and well-being of the host communities (Kingsford, Basset & Jackson, 2016). Recreational use of wetlands need not conflict with conservation objectives, but decisions concerning protection of wetlands should precede recreational planning. Ecotourism experiences should consider incorporating aspects of learning, attitude change, and behavioural change (Orams, 1995). Third, increasing the number of published studies about dissemination policies should aid effective communication to improve knowledge and awareness of stakeholders, communities, financing institutions, entrepreneurs, and manufacturers (Mediterranean Wetlands Observatory (MWO), 2016). Much of the information about dissemination policies is probably produced as ‘grey literature’ (i.e. studies not controlled by commercial publishers, and thus typically with limited distribution or not included in a bibliographical retrieval system). This study underlines the necessity of a more systematic and scientific approach to this topic (i.e. using published research papers). Finally, there were surprisingly few papers about diseases. The 17 papers retrieved mainly investigate mosquitoes as vectors of malaria (Marchi & Munstermann, 1987) or other more recent epidemics (Kelvin et al., 2012). Papers on diseases were rarely integrated with other related topics and, surprisingly, never to topics such as pollution or sustainable economy and tourism.

4.3 | Knowledge gaps and challenges: the need for integrated strategies for more effective wetland management

Wetland conservation and management may benefit from multidisciplinary research. For example, ecological integrity is a key focus of wetland conservation and management, whereby elements and processes expected in the natural habitat are maintained (Zeff, 2011). Furthermore, wetlands are interdependent human and natural systems. To maintain healthy, functioning wetlands, it is important to understand how these various natural elements and processes interact with each other and with human elements, yet few existing studies on Sardinian wetlands (<25% of papers) integrate more than one topic. Future research that combines different topics might lead to a more complete and realistic picture.

A lack of multidisciplinary research combining dissemination policies and sustainable economy and tourism with biological aspects (i.e. flora and fauna) also reflects the need for environmental policy integration in the territory involving local stakeholders. To this end, the inventory presented in this paper is a source of information on multiple topics, and incorporating it into conservation management will support the application and effectiveness of the European

Directive on SEA (Council of the European Communities, 2001). Fine-scale and multi-topic information, such as that contained in the inventory, might specifically support regional, provincial and municipal masterplans. This inventory might be included in the datasets of the Italian Institute for Environmental Protection and Research (ISPRA) and consulted by regional and provincial authorities when they are making decisions about environmental policies at various scales. International research centres and non-governmental organizations might support and, in some cases, spur policy initiatives by promoting cooperation and knowledge sharing between local experts and civil associations.

5 | CONCLUSIONS

Future research should continue to collect basic data on wetland extent, species composition and ecological condition of wetlands. This will keep the inventory up to date. There is a need for further, high-quality research on sustainable economic development (especially linked to tourism), dissemination policies and diseases: topics that are currently poorly studied in the context of Sardinian wetlands, but would contribute to more effective management and conservation. For the same reason, greater integration of multiple topics within single studies is desirable. Increased coordination amongst all stakeholders could help to facilitate multidisciplinary research. As a new frontier in the management of Sardinian and other Mediterranean wetlands, this will encourage the development of constructive approaches to the integration of economic and environmental issues. Strategic plans at the catchment level may help to fill gaps in water management, understanding threats to flows and flooding regimes. To do so, it is of critical importance to reinforce the hierarchical policy process, starting from a more decisive recognition of international commitments and obligations at national level, to the application of regional and municipal plans, bridged by integrated management strategies. To conclude, the key steps that need to be taken given the gaps found in this work are: (i) pursuing wetland inventories across the Mediterranean, especially for neglected wetland types; (ii) effective tracking of wetland ecosystem condition; (iii) establishing criteria and regulations for cultural, economic, and environmental improvement of Mediterranean wetlands; and (iv) developing more integrative research and hierarchical strategic plans.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

ORCID

Mauro Fois  <https://orcid.org/0000-0002-4178-0790>

Alba Cuena-Lombrana  <https://orcid.org/0000-0003-2750-6274>

Gianluigi Bacchetta  <https://orcid.org/0000-0002-1714-3978>

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