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An analysis of botanical studies of vascular plants from Italian wetlands

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Abstract

Wetlands are essential for life on Earth, but at the same time the most threatened environments due to the gradual alterations associated with climate change and human action. The botanical studies on wetland higher plants carried out in Italy from 1950 until today are analysed in this survey. The 1,265 contributions resulting from this study are analysed from a historical, geographical, and content point of view. Most of the scientific contributions were published in the 1980s and 1990s, often by the same research groups and on a local scale. The predominant research theme is the inventory. Most papers are mainly focused on lakes and rivers. The results of this literature survey point to the need to continue and intensify these studies, especially in southern Italy and in temporary wetlands. It is essential to make the huge amount of data resting in drawers or included in scientific reports but not published in scientific journals readily accessible. This could also be achieved through online geographical databases.

Keywords

Conservation, flora, freshwater ecosystems, Literature review, Trends in botany, vegetation

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Introduction

Wetlands are one of the most important natural habitats providing many significant benefits to the environment and humans (Mahdavi et al. 2018). The Ramsar International Convention was adopted as early as 1971 for their protection. This Convention defined 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 salty, including areas of marine water the depth of which at low tide does not exceed six meters" (Gardner and Finlayson 2018). Wetlands cover about 6% of the Earth's surface and include mangroves, peatlands and marshes, rivers and lakes, deltas, floodplains and flooded forests and even coral reefs. A wetland is a generalized concept including internal and coastal areas. It is distributed in every climatic region, ranging from the polar zones to the arid ones (Gokce 2019).

Purification of water, reduction of flood risk, protection of shorelines, conservation of soil and water, filtration of sediment, removal of pollution, as well as aesthetic and recreational values are only some of the benefits associated with wetlands (Grenier et al. 2007; Powers et al. 2012; Ji et al. 2015). Wetlands are also the main habitat for hundreds of plants and animals, including one-third of all species at risk (Ozesmi and Bauer 2002; Reimer 2009; Kingsford et al. 2016). Due to their vital biological and ecological functions, wetlands have been called the "kidneys" of nature (Mitsch and Gosselink 2000) and are important indicators of environmental health (Touzi et al. 2007). Early civilizations were established near rivers, lakes and floodplains (Keddy 2010; Gokce 2019). The Mesopotamian civilization is consensually accepted to have started between the Euphrates and Tigris rivers; the other ancestral civilization, Egypt, commenced in the Nile Valley. The fact that civilization started in these regions is a reflection of how important the aquatic habitat is for biotic diversity. Therefore, wetlands are very critical ecosystems and some of them are the most productive habitats (Gokce 2019).

Despite the number of ecosystem services provided by wetlands, they were widely regarded as undesirable in the past and were frequently drained to be replaced with other types of land use, such as urban space and agriculture (Mitsch and Gosselink 2000; Dechka et al. 2002; Fraser and Keddy 2005; Ji et al. 2015). The reasons for wetland loss and deterioration include excessive use, land degradation, climate change, drought, salinization, eutrophication, pollution, decreased biotic diversity, and invasive exotic species (Mahdavi et al 2018; Gokce 2019; Praleskouskaya and Venanzoni 2021). In recent years, attention has been focused on temporary small ponds as important biodiversity sources (Bagella et al. 2009).

Since wetlands are complex multifunctional systems, they are likely to be the most beneficial if conserved as integrated ecosystems rather than as individual component parts (Gokce 2019). From all this emerges the need to know the distribution of these important environments and to monitor their state of health in order to adopt appropriate management and conservation strategies. Wetlands can also be monitored through the study of the plant component. Wetland vegetation, indeed, plays a basic role in aquatic ecosystem ecology (Lastrucci et al. 2018). In particular, wetlands

represent an important factor in providing food and shelter for the aquatic fauna (Carpenter and Lodge 1986). Wetland plants also influence hydrological and sediment processes by regulating water flow, crest stability, and soil formation (Saaltink et al. 2018). Wetland plants are endangered by the same forces that generally threaten these ecosystems, including human activities such as wetland draining or filling, hydrologic alterations, chronic degradation due to nonpoint source pollution, and invasion of exotic species (Cronk and Fennessy 2016; Bolpagni et al. 2018; Cuena-Lombraña et al. 2021). Agriculture, housing, industry and tourism are the main drivers responsible for hydrological alterations (Msofe et al. 2019).

Italy is recognized as one of the prominent hotspots for plant diversity at regional and global scales, hosting a rich and diverse range of ecosystems and habitat types (Pedrotti 1971). This is precisely the case of aquatic habitats, which represent a major portion of the total water surfaces in the Mediterranean region (Bolpagni et al. 2018). All national and local floras also include wetlands, but in this survey, we wanted to analyse the scientific contributions specifically dedicated to wet environments.

The state of knowledge on the plant biodiversity of wetlands in Italy is fragmentary. Pignatti's (1952–1953) work represents a milestone among the phytosociological monographs of wet areas in Italy. Montanari (1988a, 1988b) published a review of the botanical knowledge of Italian rivers. Corbetta and Pirone (1988) and Pirone and Frattaroli (1988) issued a compendium on the vegetation of rivers and freshwater wetlands of Abruzzo. The flora and vegetation of the watercourses of Sicilia, Calabria, and Basilicata were analysed by Ferro and Di Benedetto (1980), Brullo and Spampinato (1990, 1997), and Ferro and Parisi (2002). Sburlino et al. (2004, 2008) dealt with the aquatic and marshy vegetation of north-eastern Italy. Tomei and Kugler (2005) published a synthesis of the botanical knowledge of the wetlands of Toscana. Venanzoni et al. (2018) reviewed the marshy and wet vegetation described or present in Italy. Ciaschetti et al. (2021) summarized current knowledge on the sedge vegetation of the 'Major Highlands' of Abruzzo. Recently, Cuena-Lombraña et al. (2021) published a compendium of research results for the Sardinian wetlands. Hence, the need for a review that would encompass the entire national territory. The 1,152 contributions presented and analysed here seem highly indicative of current knowledge about Italian wetland habitats. A survey going further back in time with respect to the contributions reported in this review would certainly have increased the total number of scientific papers, but would not change, in any meaningful way, the general significance of the research results.

Materials and methods

Research area and taxa

The Italian territory consists of a continental part that includes the Alpine arc, the Po-Venetian plain, Liguria, and the upper portion of the Apennines. The large part of Italy is a peninsula, *ca.* 1,000 km long and 170 km wide, with northwest-southeast ori-

entation at the centre of the Mediterranean Basin and 7,458 km of coastline; there are also two large islands, Sardegna and Sicilia, and more than 800 islets. The territory is predominantly hilly (41.6%), partly mountainous (35.2%), and slightly flat (23.2%).

It is the richest country in wetlands amongst those of the Mediterranean Basin. It counts 69 natural lakes equal to or larger than 0.5 km^2, 183 artificial basins larger than 1 km^2, and more than 230 rivers and streams of particular relevance: 58 exceeding 100 km in length, and 75 with average daily discharges greater than 10 $m^3 s^{-1}$ (Bolpagni et al. 2018). On the whole, 57 sites were designated as Wetlands of International Importance (Ramsar Sites) (http://www.ramsar.org/). Italy is the second highest area, after the Iberian Peninsula, in terms of plant species richness in Europe (Bilz et al. 2011). The entire checklist of plants includes 9,948 specific and subspecific taxa, 8,288 native species and 1,660 alien species (Bartolucci et al. 2018; Galasso et al. 2018, and subsequent updates merged into the Portal to the Flora of Italy, http://dryades.units.it/floritaly/index.php). The first comprehensive inventory of aquatic plants on anationwide scale resulted in 279 specific and subspecific taxa estimated at 88.5% of the total European and Mediterranean aquatic taxa (Bolpagni et al. 2018). The two main islands also have an important biological heritage linked to aquatic habitats. As many as 13,981 wetlands have been inventoried in Sardegna and Sicilia (https://italiaiswet.it), covering in these administrative regions a total surface of about 645.96 km^2 (*ca.* 1.3% of their territory).

Literature data

The reference list published by the Italian Botanical Society (Scoppola and Magrini 2005) was used as starting point for this review. This was supplemented with Albano et al. (2007) and the databases available online. The historical period investigated extends from 1950 to May 2022. Older literature would have brought an excessive amount of "noise" due to environmental variations that occurred over time mainly due to the change in land use and remediation to contrast malaria.

The online research was carried out, both with Italian and English terms, in Web of Science (https://www.webofscience.com/wos/woscc/basic-search), Scopus (https://www.scopus.com/search/form.uri), as well as in Google Scholar (https://scholar.google.com) with the terms, singular or plural: 'amphibian', 'barrage', 'dam', 'delta', 'estuary', 'freshwater', 'lagoon', 'lake', 'marsh', 'pond', 'pool', 'reservoir', 'river', 'saline', 'swamp', 'torrent', 'water', 'wetland', or combined with 'Italy', 'Sardegna', 'Sicilia' and 'botanical', 'flora', 'phyto', 'plant', and 'vegetation'. Further additions were made using the indexes of the journals reported in Scoppola and Magrini (2005), which were only partially included in the online databases. 'Gray literature', such as technical reports, and academic theses, was not considered. After duplicate removal, title screening and abstract revision, the single papers were classified by wetland type and topic. Research was focused on higher plants and current vegetation. Algae, bryophytes, fungi, and palynological studies were not included. Only research specifically aimed at studying wetlands was included. Contributions on large areas that also include wetlands, as well as national and regional floras, were also not included.

The wetland study sites of each paper that could be identified were georeferenced in Google Earth (https://earth.google.com) and overlaid on the network of protected areas on QGIS 3.26 (https://www.qgis.org). Spatial datasets were downloaded from the national geoportal (http://www.pcn.minambiente.it/mattm/) and included all protected areas (Natura 2000, Ramsar sites, National and Regional Parks and Nature Reserves). The list is available as Suppl. material 1.

Types of wetlands and research themes

According to the European habitat types (Habitat Directive 92/43/EEC, and the online Italian interpretation manual available at http://nvr.unipg.it/habitat/), wetland types described in the analysed papers were identified as: 'River' for streaming waters corresponding to the habitats 3220, 3230, 3240, 3250, 3260, 3270, 3280, 3290, 91E0, 91F0; 'Estuarine waters' for mixed fresh and marine waters in estuaries or deltas (habitat 1130); 'Lakes and ponds' for standing perennial waters (habitats 3110, 3120, 3130, 3140, 3150, 3160); 'Saline' for inland or coastal saline waters (habitats 1150, 1310, 1320, 1340, 1410, 1420, 1430, 1510); 'Bogs' for waterlogged grounds (habitats 7110, 7120, 7140, 7150, 7210, 7220, 7230, 7240), 'Rice fields' for waterlogged ground cultivations and 'Temporary' for standing temporary waters, temporary pools, or temporary ponds (habitat 3170). Habitat distribution data was retrieved from the EU Reporting Nature Directive 2013–2018 by ISPRA (Angelini et al. 2016; http://reportingdirettivahabitat.isprambiente.it/downloads) in terms of 10 × 10 km cells. An estimate in relative terms of how rich the individual regions of freshwater habitats are and how much these have been studied was obtained by dividing the number of cells containing freshwater habitats by the total number of cells present and dividing the number of cells with freshwater habitats by the number of cells that contain at least one locality that appears in literature.

Dunes and rocky coasts were not considered in this review, while humid areas behind them were included in the previous categories according to their nature. The distinction between natural environments and human-made ones used in the Ramsar classification (Ramsar Convention Secretariat 2010, 2013) seemed to us of little use for the purposes of biological investigation in Italy because all the wetlands considered have undergone heavy modifications by humans; only rice fields have been pointed out.

We classified all contributions according to their focus into four research themes: conservation, ecology, inventory, and taxonomy; multiple classifications were also adopted when there were more several predominant topics (see details in Table 1).

Results

We found 1,265 scientific contributions dealing with higher plants in Italian wetlands, published between 1950 and 2022. The largest number of contributions, 554, was published in the 20 years between 1980 and 1999, 276 of which in the 1980s and 278 in the 1990s (Fig. 1).

Table 1. Data on the presence of freshwater habitats by administrative region and related published studies. The 10 × 10 km grid cell and the occurrence of freshwater habitats is according to Angelini et al (2016).

Region	No. of cells	No. of cells with freshwater habitats	No. of cells with published studies	% of cells with freshwater habitats	% of cells with freshwater habitats having published studies
Abruzzo	141	108	22	76.60	20.37
Basilicata	128	55	8	42.97	14.55
Calabria	193	124	18	64.25	14.52
Campania	169	96	4	56.80	4.17
Emilia-Romagna	275	226	53	82.18	23.45
Friuli Venezia Giulia	107	103	19	96.26	18.45
Lazio	221	133	32	60.18	24.06
Liguria	87	81	10	93.10	12.35
Lombardia	300	280	65	93.33	23.21
Marche	122	82	11	67.21	13.41
Molise	62	52	3	83.87	5.77
Piemonte	310	297	34	95.81	11.45
Puglia	245	132	24	53.88	18.18
Sardegna	305	193	37	63.28	19.17
Sicilia	333	295	60	88.59	20.34
Trentino-Alto Adige	171	161	43	94.15	26.71
Toscana	291	246	63	84.54	25.61
Umbria	108	68	20	62.96	29.41
Valle d'Aosta	48	48	7	100.00	14.58
Veneto	232	208	46	89.66	22.12

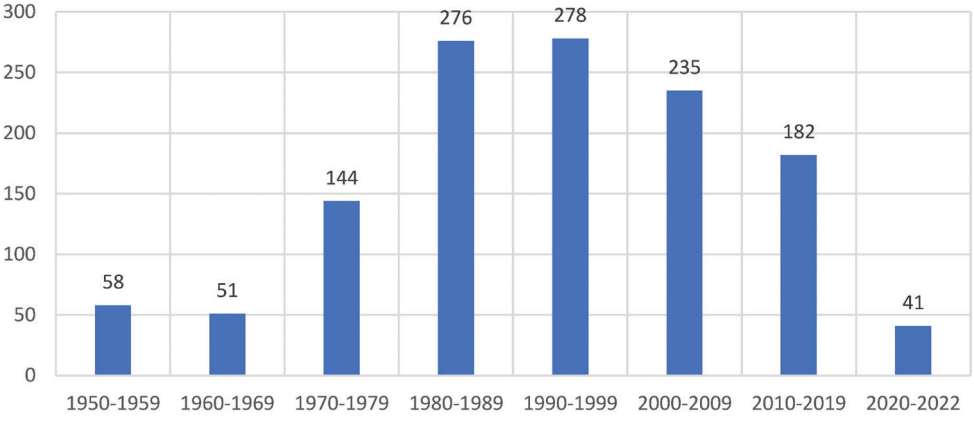
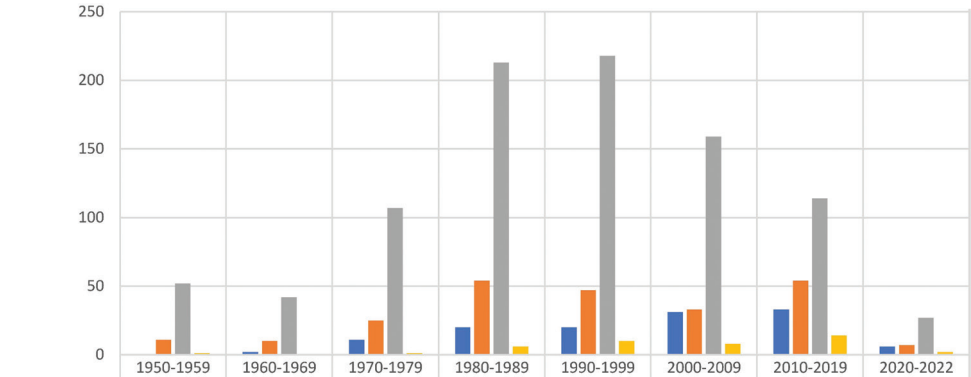


Figure 1. Number of scientific contributions published per decade from 1950 to today.

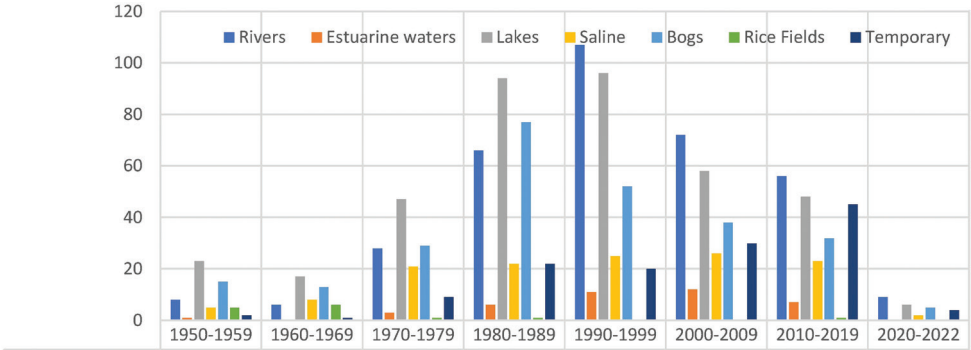
Research has always been carried out on a local or regional basis. Many contributions have been published by the same research groups that have focused on one area and on neighbouring geographic areas.

The predominant research theme in all the years considered are floristic and vegetational inventories (932 papers). Studies on ecology, and conservation follow, with 241 and 123 contributions, respectively (Fig. 2). It is interesting to note how the trend of



	1950-1959	1960-1969	1970-1979	1980-1989	1990-1999	2000-2009	2010-2019	2020-2022
Conservation	0	2	11	20	20	31	33	6
Ecology	11	10	25	54	47	33	54	7
Inventory	52	42	107	213	218	159	114	27
Taxonomy	1	0	1	6	10	8	14	2

Figure 2. Number of scientific contributions classified per topic per decade from 1950 to today. The totals are higher than the contributions published because the same paper could be classified in more than one topic.



	1950-1959	1960-1969	1970-1979	1980-1989	1990-1999	2000-2009	2010-2019	2020-2022
Rivers	8	6	28	66	107	72	56	9
Estuarine waters	1	0	3	6	11	12	7	0
Lakes	23	17	47	94	96	58	48	6
Saline	5	8	21	22	25	26	23	2
Bogs	15	13	29	77	52	38	32	5
Rice Fields	5	6	1	1	0	0	1	0
Temporary	2	1	9	22	20	30	45	4

Figure 3. Number of scientific contributions per wetland type. For the definition of wetland types see Materials and methods.

conservation studies has increased significantly from 1980 onwards in parallel with the general awareness of the role of nature conservation. Studies on the topic of taxonomy are always the fewest and only reach 42 papers (Fig. 2).

As regards wetland types, the largest number of papers are mainly focused on lakes and ponds (389) and rivers (352); bogs, temporary wetlands, and saline habitats account for 261, 133 and 132, respectively (Fig. 3). Papers on estuarine waters (40) and

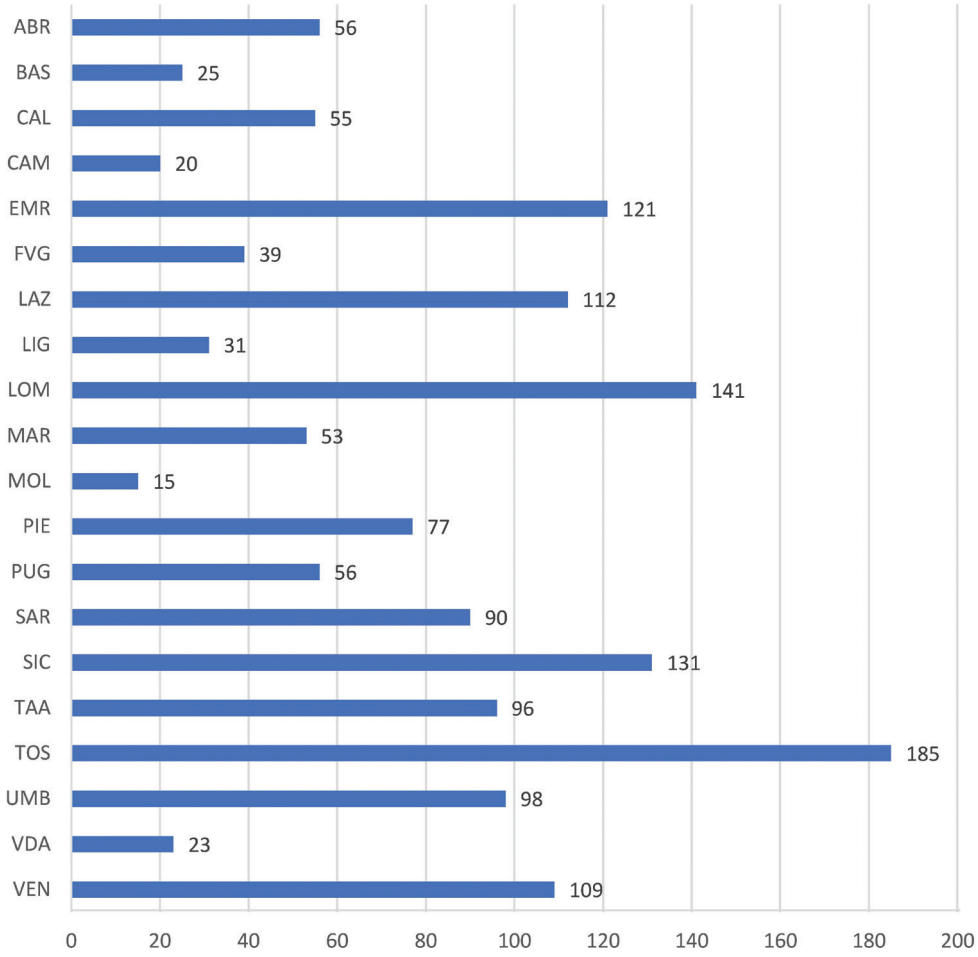


Figure 4. Number of scientific contributions per administrative region of Italy.

rice fields (14) are less represented (Fig. 3). Although papers on rivers, together with those on lakes, are the most frequent over the entire period, those on rivers were overcome by those on bogs in the 1950s, 1960s and 1970s. From the '90s to the present day, papers on rivers become the main ones, surpassing even those on lakes (Fig. 3).

As regards the distribution of studies in the different Italian administrative regions, the greatest number concerns Toscana (185), followed by Lombardia (141) and Sicilia (131) (Fig. 4). Emilia Romagna (121), Lazio (112), and Veneto (109) also exceed 100 papers. Molise (15), Campania (20), Valle D'Aosta (23), and Basilicata (25) are the regions for which the lowest number of papers have been published (Fig. 4).

As shown in Fig. 5, 998 contributions could be mapped to specific areas; the remaining 267 papers refer to areas that are too large, or generic. The contributions were attributed to 593 geographical areas. These areas are well distributed in northern

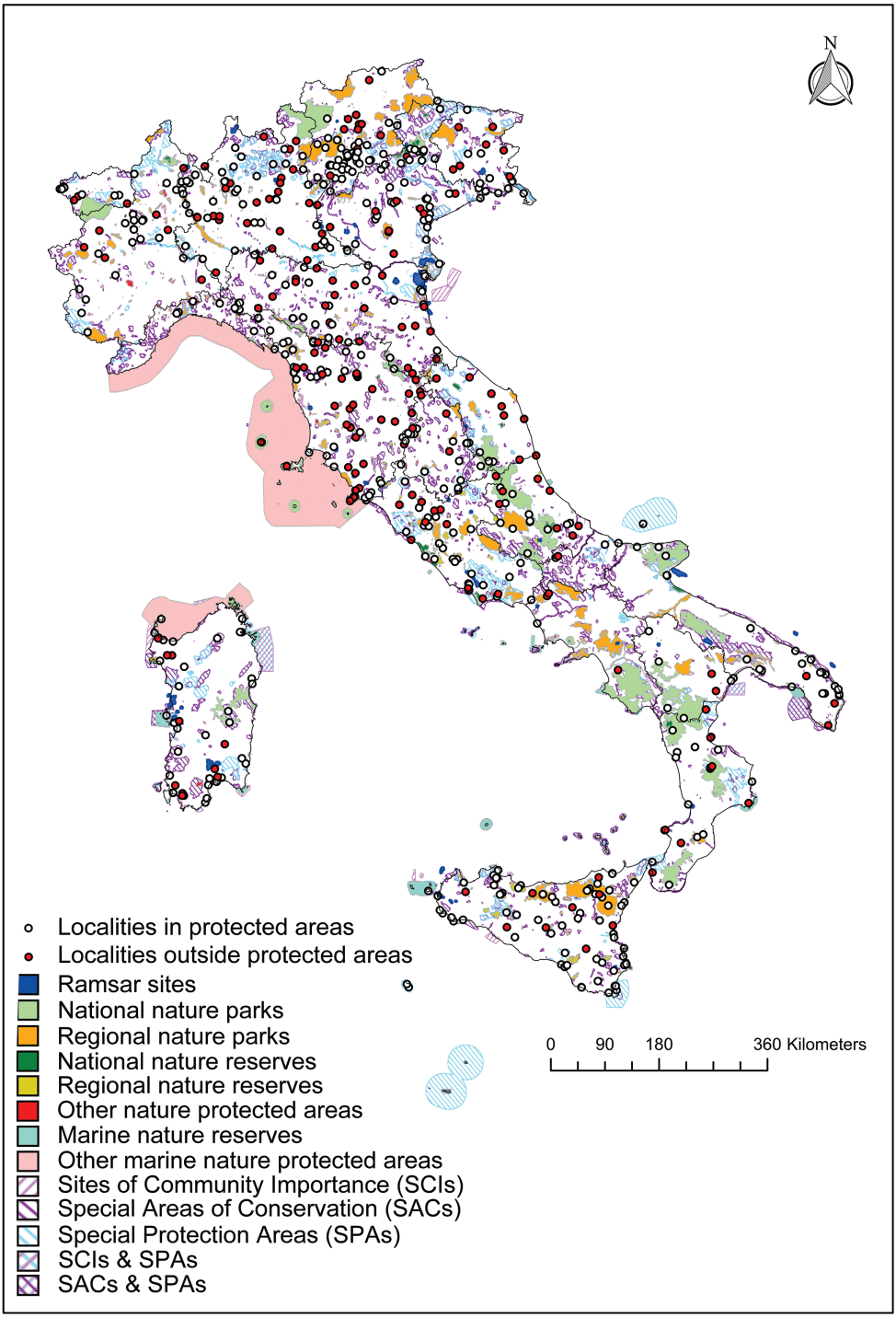


Figure 5. Distribution of scientific contributions for the Italian territory in relation to protected areas.

and central Italy and in Sicilia; the southern part of Piemonte, Campania, Basilicata and the northern part of Puglia record few studies. The most studied area is Lake Trasimeno with 27 papers. Other well investigated areas are the Tiber River (11 papers) and the Valleys of Comacchio (10 papers), Lake Massaciuccoli (9) and the Colfiorito swamp (8). In all other cases there are insufficient data to make diachronic floristic studies.

Almost all of the 57 Ramsar sites recognized in Italy have been investigated with at least one contribution included in the list. There are, in fact, 68 contributions concerning them. Of the 998 mapped contributions, 218 refer to areas without any legal protection. These are mostly areas that fall along the course of rivers or within swampy areas. As shown in Table 1 and Fig. 6, many regions of northern Italy (Emilia Romagna, Friuli Venezia Giulia, Liguria, Lombardia, Piemonte) and Molise and Sicilia have a percentage of cells in which at least one freshwater habitat has been mapped higher than 80%. The regions that show the highest percentages of cells in which falls at least one studied locality are Umbria (29.41%), Trentino Alto Adige (26.71%), Toscana (25.61%), and Lazio (24.06%); those with the lowest percentages are Campania (4.17%), Molise (5.77%), Liguria (12.35%), Calabria (14.52%), and Basilicata (14.55%).

Conclusions

Italian wetlands are among the most threatened habitats, although many of them have been investigated and several fall within protected areas. In recent years, climate change is further worsening the situation by altering the dynamics of perennial humid environments and making temporary ones disappear (Calhoun et al. 2017). Environmental conservation passes through knowledge. Some habitats, like the Tiber river, have been the subject of a greater number of articles, also thanks to their proximity to research centres, but entire areas in southern Italy are still under-investigated. The results of this review highlight the need to intensify botanical research in Italian wetlands, especially in southern Italy and in protected areas, although the situation is already changing. In this year's Congress of the Italian Botanical Society, as many as 12 contributions concerned the theme of freshwater plants and habitats (Chiarucci et al. 2022). Certainly, many investigations not considered here have been carried out but have remained in the so called "grey literature" (thesis, internal documents, forms, etc.). In recent years, the need for researchers to publish in indexed international journals has discouraged studies conducted at the local level; however, data of local interest form the basis of global knowledge on wetlands. Publishing the contents of these documents is necessary to make them easily and freely accessible to the scientific community and the general public. This can be helped by biodiversity databasing and mapping projects in Italy such as Wikiplantbase #ItaliA (http://bot.biologia.unipi.it/wpb/italia/index.html), anArchive (http://www.anarchive.it), VegItaly (http://www.vegitaly.it) or LISY (http://www.scienzadellavegetazione.it/sisv/lisy/).

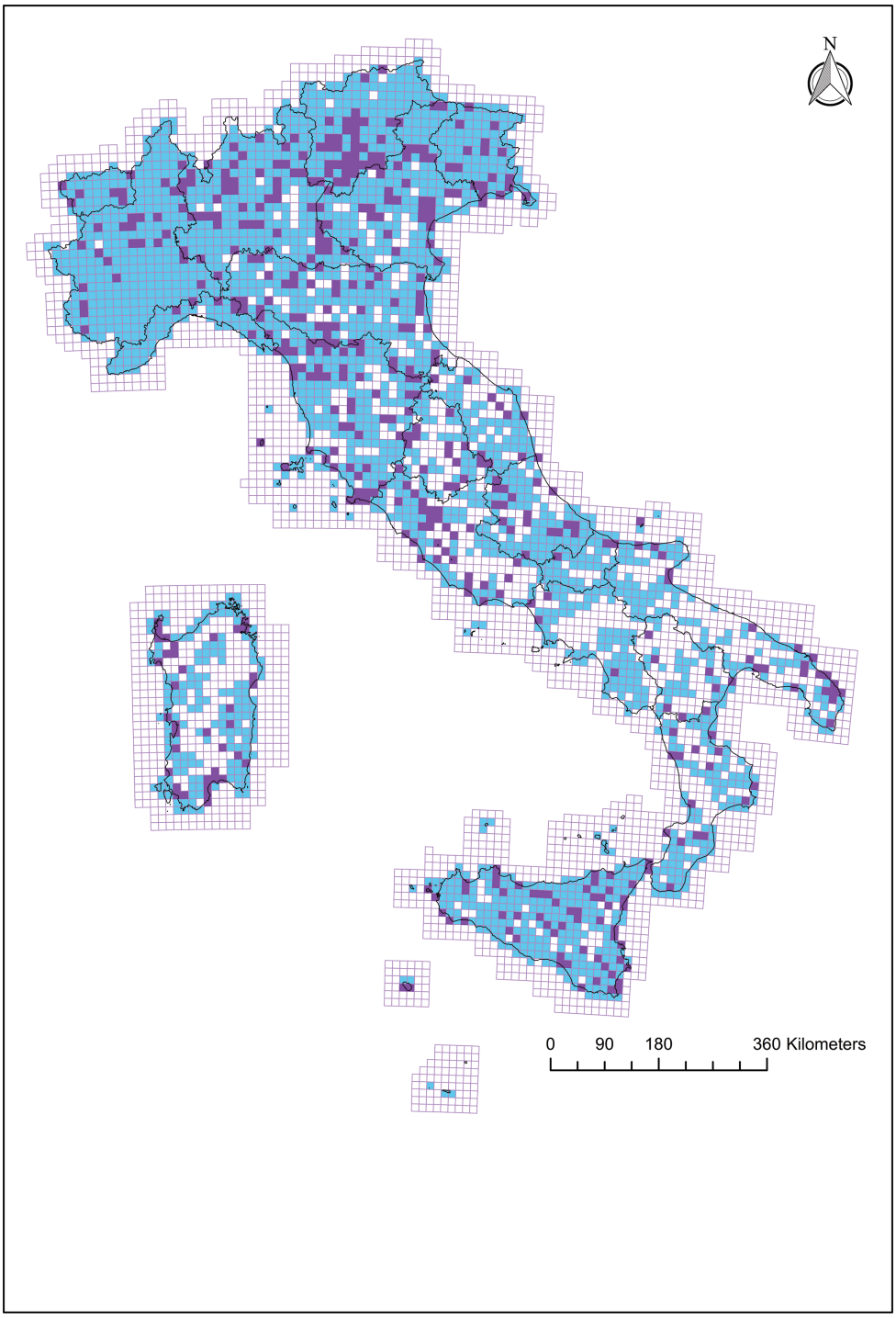


Figure 6. Distribution of the 10-km^2 cells with at least one freshwater habitat mapped (light blue) and of the cells including at least one studied locality (purple).

The National Biodiversity Future Center was established last June, funded by the National Recovery and Resilience Plan (NRRP) and including a network of 48 partners. It has the purpose of implementing national scientific research on biodiversity. The freshwater biodiversity theme is one of the most heartfelt. In the first three years of activity, research aimed at studying biodiversity at all levels on freshwater environments in Italy will be funded to improve current knowledge levels.

Basic data on biodiversity contextualized within a local socio-economic framework will sustain future management plans for the exploitation of natural resources that take into account the responsible use of aquatic ecosystems and the protection of the biological heritage associated with them. All over the world, the conservation and responsible use of humid environments can act as a driving force for the sustainable development of these realities (Duim van der and Henkens 2007).

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Supplementary material 1

List of data references on botanical studies of higher plants in Italian wetlands

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