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Native and alien nymphaeids in a Mediterranean island: distribution, ecology and status in Sardinia (Italy)

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Abstract

After a long-term monitoring campaign spanning 1999-2025, the populations of Nymphaeids growing in Sardinia were comprehensively investigated. Within the family Nymphaeaceae, *Nuphar lutea* and *Nymphaea alba* are native species on the island, while two other taxa are alien: *Nymphaea mexicana* and *N.* × *marliacea*, both currently naturalized in Sardinia. Two additional taxa, one native (*Nymphoides peltata*) and one alien (*Nelumbo nucifera*) remain unconfirmed: the former was reported only once in 1827, and the latter was recorded as naturalized twenty years ago, but with no precise location or subsequent observations. Overall, we recorded the occurrence of *N. alba* at 173 sites (eight of which are now locally extinct) and *N. lutea* at 38 sites (two of which are now locally extinct). Regarding *N. alba*, its populations in northern Sardinia have all been described in detail, with numerous metapopulations documented, particularly within the hydrographic basins of the Coghinas, Temo, and Posada rivers, as well as in other smaller basins. Moreover, some stations in South Sardinia have been confirmed after more than a century. In addition, *N. candida* is definitively excluded from Sardinian flora. As for *Nuphar lutea*, its localities have been further refined, all concentrated in the Coghinas River basin, whereas the only known sites in the South have now disappeared. Moreover, an updated and verified distribution of exotic waterlily populations in Sardinia is provided. Furthermore, the ecological requirements, the main threats and conservation issues affecting native taxa on the island are identified.

Key words: waterlilies; macrophytes; chorology; freshwater ecosystems; insular biodiversity.

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Introduction

Wetlands are among the most exposed ecosystems worldwide, undergoing substantial transformations driven by land-use change, hydrological alterations, and climate change (Dudgeon *et al.*, 2006; Xu *et al.*, 2019; Dahal *et al.*, 2025). Riverine systems, in particular, are increasingly affected by pollution, channelization, culverting, damming, and impoundments, as well as by extreme hydrological events such as floods, which, exacerbated by the effects of climate change, may irreversibly reshape their morphology and functions (Döll and Zhang, 2010; Reid *et al.*, 2019). These processes have particularly strong consequences for aquatic macrophytes with narrow ecological requirements.

Within freshwater habitats, Nymphaeids (waterlilies) are rooted aquatic macrophytes forming basal rosettes, with leaves that are predominantly floating or emergent and supported by long petioles enabling contact with the water surface (Van der Velde, 1978). Nymphaeid taxa contribute to aquatic plant biomass and productivity, act as regulators of light availability through shading, modulate nutrient dynamics, provide habitat and refuge for various trophic levels, and improve water quality (Henriot *et al.*, 2019).

In Europe, these taxa belong to the orders Asterales (native, family Menyanthaceae), Nymphaeales (native and alien taxa, family Nymphaeaceae), and Proteales (alien, family Nelumbonaceae). The family Nymphaeaceae, a significant group of strictly aquatic plants (Borsch *et al.*, 2008), comprises nearly 70 macrophytes worldwide (Schneider and Williamson, 1993). Despite its cosmopolitan distribution, only a limited number of Nymphaeaceae taxa occur in Europe, represented by two genera (*Nymphaea* and *Nuphar*) and six confirmed taxa: *Nuphar lutea* L., *N. pumila* (Timm) DC., *Nymphaea alba* L., *N. candida* C.Presl, *N. lotus* L., and *N. tetragona* Georgi (Tutin *et al.*, 1993). Italy hosts only two native species, *N. alba* and *N. lutea*, both occurring in Sardinia (Bartolucci *et al.*, 2024). In a recent past, however, these taxa were mistakenly reported as extinct, doubtful or casual aliens on the island (Tutin *et al.*, 1993; Desfayes, 2008; Bartolucci *et al.*, 2018), and *N. alba* is still listed as extinct in Sardinia by Plants of the World Online (https://powo.science.kew.org/), highlighting the persistence of floristic uncertainties regarding their actual status on the island and the need for a deeper update.

In addition to native species, the introduction of ornamental plants has occasionally led to the naturalization of alien taxa, and hybridization involving exotic species may pose a threat to native populations (Yakandawala *et al.*, 2017). In Italy, three alien taxa have been recorded, *Nymphaea mexicana* Zucc., *N.* × *marliacea* Lat.-Marl., and *N.* × *thiona* D.B.Ward., the latter occurring only in Lombardy as a casual (Galasso *et al.*, 2024).

Among the Menyanthaceae, only *Nymphoides peltata* (S.G.Gmel.) Kuntze is reported in north-central Italy and Sardinia, occurring primarily as a native species and more rarely as a naturalized alien, specifically in Calabria, Friuli-Venezia Giulia, and Trentino-Alto Adige (Bartolucci *et al.*, 2024).

Nelumbo nucifera Gaertn. (Nelumbonaceae) is the sole representative of its family and occurs in Italy as an alien species (Galasso *et al.*, 2024), but its actual occurrence and degree of establishment in Sardinia remain poorly documented.

This study aimed to compile and verify all available historical and bibliographic data on native and alien Nymphaeids in Sardinia, complemented by recent data obtained through an extensive field sampling campaign. The objectives were to produce an updated distribution map, assess their current status, their ecological requirements, and identify the main threats to native taxa, with a primary focus on their floristic and chorological reassessment.

METHODS

Study area

Sardinia is located in the central-western Mediterranean Basin and covers a total area of 24,090 km^2, with a coastal perimeter of 1,846 km. Sardinia lacks high mountains, the highest peaks being located in the Gennargentu Massif (P. La Marmora, 1,834 m), Supramonte (Monte Corrasi, 1,463 m), and Mount Limbara (P. Balistreri, 1,359 m). Areas above 600 m asl account for 13.6% of the territory, while hills and plateaus cover 67.9%. Lowland areas occupy 18.5% of the island, the most extensive being the Campidano, Cixerri, Logudoro, Nurra, and the Ottana plain (Bacchetta *et al.*, 2009).

The morphological profile of Sardinia is marked by pronounced contrasts: the eastern part is mostly dominated by Precambrian metamorphic rocks, Variscan granitoids, and, to a lesser extent, Mesozoic limestones forming residual reliefs of varying prominence. Conversely, the western sector is mostly characterized by volcanic and sedimentary rocks of Tertiary age, primarily Oligocene and Miocene. Palaeozoic lithologies are also prominent locally, and in south-western Sardinia reliefs are characterized by metamorphosed sedimentary rocks (Carmignani *et al.*, 2016), resulting in a wide variety of geomorphological settings that influence river morphology and freshwater habitats.

The principal watercourses of Sardinia, listed from North to South, are the Liscia, Coghinas, Temo, Tirso, Cedrino, Flumendosa, Flumini Mannu of Samassi-Serramanna, Cixerri, etc. Numerous artificial reservoirs are located along many of these watercourses and elsewhere (Fois *et al.*, 2021), playing a major role in shaping the availability of lentic habitats for aquatic macrophytes, whereas only the small Baratz Lake (40 ha) can be regarded as a natural lake. However, the island also hosts several endorheic basins (i.e., lacustrine basins with predominantly brackish waters and no surface outlets), together with numerous coastal lagoons and ponds, the largest of which are located near the gulfs of Cagliari, Oristano, and Palmas (Bacchetta *et al.*, 2009).

Climatically, Sardinia is characterized by the interaction between the Mediterranean Pluviseasonal Oceanic bioclimate, covering 99.1% of its surface, and the Temperate Sub-Mediterranean bioclimate, found above 1,000-1,200 m asl. In turn, it is divided in a transitional Temperate Sub-Mediterranean belt in the northern and central mountain ranges, and a Temperate Oceanic, restricted to the summit areas of the highest peaks, and occupying less than 1% (Canu *et al.*, 2015; Bazzato *et al.*, 2021). The island exhibits a markedly bi-seasonal regime, with mean annual temperatures (1971-2000 period) ranging from 11.6°C to 18.0°C and mean annual precipitation varying from 411 mm to 1,215 mm (Canu *et al.*, 2015), conditions that strongly influence the hydrological permanence of water bodies colonized by macrophytes.

Data collection

We initially collected all the bibliographic information available from literature including historical sources (e.g., Moris, 1837-1859; Mola, 1919; Desfayes, 2008) and from herbaria, in particular CAG, FI, SASSA, and SS (herbaria codes follow the NYBG Steere Herbarium; https://sweetgum.nybg.org/science/ih/). Moreover, we checked and verified all significant reports (only in natural and semi-natural contexts) from websites such as Wikiplantbase (https://www.gbif.org/dataset/ea04653c-58f5-4f14-9ed0-39f85871f1db), iNaturalist (https://www.inaturalist.org/) or floristic pages on Facebook (Flora Spontanea della Sardegna; https://www.facebook.com/share/g/1CRDMz1HM5/), retaining only records supported by photographic evidence, herbarium material, or subsequent field verification. In particular, all relevant sites identified through online sources were further verified in the field to confirm species identification. In some cases, living material was also collected and conserved in the Botanical Garden of Cagliari.

A long-lasting fieldwork, corroborated by precise georeferencing and detailed descriptions of each site's ecological conditions and associated vegetation communities, was achieved from 1999 to 2025. Collected herbarium specimens are preserved in the SS herbarium and in personal herbaria (Herb. Calvia, Herb. Mascia). Repeated surveys over time allowed the confirmation, updating, or exclusion of historical and recent records. This comprehensive dataset provides a robust basis for assessing species' presences, habitat preferences, distribution patterns, and potential environmental factors influencing the occurrence and conservation status of these taxa.

Plant specimens were identified through the use of European and Italian floras (e.g., Tutin *et al.*, 1993; Arrigoni, 2006; Pignatti, 2017). The nomenclature follows Bartolucci *et al.* (2024) and Galasso *et al.* (2024).

All province codes cited, in brackets, in this work follow the establishment of two metropolitan cities, and six provinces, after the enactment of the Regional Law 7/2021, in force since June 1, 2025: Cagliari (CA) and Sassari (SS); provinces of Nuoro (NU), Oristano (OR), Olbia-Tempio (OT), Medio Campidano (VS), Ogliastra (OG), and Sulcis-Iglesiente (SU).

RESULTS

During our research, we found bibliographic data about six different nymphaeid taxa in Sardinia, three of which are native (*Nuphar lutea*, *Nymphaea alba*, and *Nymphoides peltata*), while three are alien (*Nelumbo nucifera*, *Nymphaea mexicana*, and *N.* × *marliacea*). Based on field surveys, we confirmed the current occurrence of four taxa, while two are currently extinct on the island, specifically *N. nucifera* and *N. peltata*.

Native species

Nuphar lutea (L.) Sm. (Nymphaeaceae)

Historical data: In Sardinia, *Nuphar lutea* was first recorded by Moris (1827), Mola (1919), and Arrigoni (2006-2015) from parts of the Coghinas river basin.

In the South, Bacchetta (2006) reported the species as naturalized near Poggio dei Pini (Capoterra, CA), where it was erased by a heavy flood in 2009. Then, the species was considered as in need of confirmation (Desfayes, 2008), as doubtful (Puddu *et al.*, 2016), and casual alien (Bartolucci *et al.*, 2018). Its definitive reinstatement as a native was due to Bartolucci *et al.* (2019).

Current distribution: The species occurs in 38 sites within the Coghinas River basin, where rich populations exist along its two branches and on the main river for long stretches (Fig. 1; Tab. 1), confirming most of the historical records.

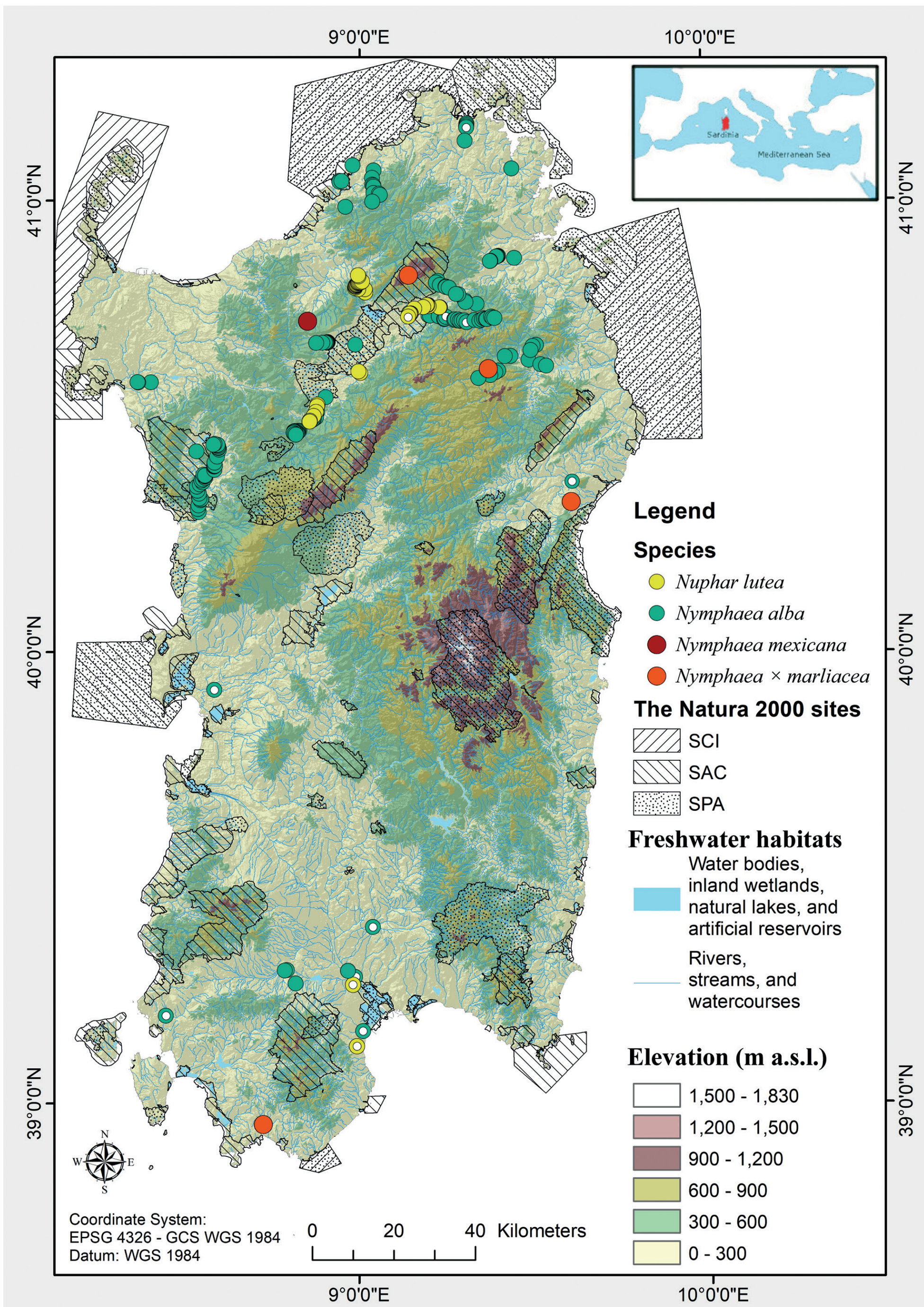

Fig. 1. Distribution map of the nymphaeid taxa currently occurring in Sardinia. Pointed circles refer to not confirmed data.

Tab. 1. Distribution and local persistence of native and alien nymphaeids recorded in Sardinia, organized by hydrographic unit and site. For each taxon, the table reports status, location (hydrographic unit, site, municipality), number of sites, elevation range, habitat, first record, local persistence, and the number of sites outside (A) and inside (P) protected areas. New records correspond to occurrences documented for the first time in this study. In some cases, sites first documented in this study are currently not confirmed and likely extinct; these refer to locations where the species was first observed during this study but was no longer found during subsequent surveys, suggesting extinction prior to formal documentation.

Taxon	Status	Hydrographic unit	Site	Municipality	N. of sites	Elevation (m asl)	Habitat	First record	Local persistence	Protected areas (A/P)
Nymphaea alba	Native	Liscia River	Liscia	Palau	6	1-5	River mouth, secondary riverbed	Desfayes (2008), 1 site	Partially extinct (5 extant, 1 extinct)	A
Nymphaea alba	Native	Rio S. Giovanni	Saloni Pond	Arzachena	1	8	Permanent pond	New record (this study)	Currently occurring	A
Nymphaea alba	Native	Rio Li Cossi	Rio Li Cossi	Trinità d'Agultu	7	0-78	Stream pools, stream mouth	New record (this study)	Currently occurring	P
Nymphaea alba	Native	Riu di la Poltrona	Riu di la Poltrona	Trinità d'Agultu	1	7	Stream pool	New record (this study)	Currently occurring	P
Nymphaea alba	Native	Rio Turrali/Vignola	Rio Vignola	Aglientu	9	52-362	Stream pools	New record (this study)	Currently occurring	A
Nymphaea alba	Native	Rio Pirastru	Riu Pirastru	Trinità d'Agultu	2	175-196	Stream pools	Arrigoni (2006-2015)	Currently occurring	A
Nymphaea alba	Native	Pandrongianus	Riu Vaddi Santa	Tetli	6	88-220	Stream pools	New record (this study)	Currently occurring	A
Nymphaea alba	Native	Pandrongianus	Rio San Simone	Olbia	1	29	Secondary riverbed	New record (this study)	Currently occurring	A
Nymphaea alba	Native	Coghinas River	Rio Terramala	Berchidda	10	270-447	Stream pools	New record (this study)	Currently occurring	6 A, 4 P
Nymphaea alba	Native	Coghinas River	Rio S'Eleme/Badu Pedrosu	Alà dei Sardi, Monti, Berchidda	24	192-487	Stream pools	Desfayes (2008), 1 site	Partially extinct (23 extant, 1 extinct)	A
Nymphaea alba	Native	Coghinas River	Riu of Berchidda	Berchidda	2	190-200	Secondary riverbeds	New record (this study)	Currently occurring	A
Nymphaea alba	Native	Coghinas River	Riu Mannu of Berchidda	Berchidda	1	169	Secondary riverbed	New record (this study)	Currently occurring	A
Nymphaea alba	Native	Coghinas River	Riu Mannu of Ozieri/Mores Ittireddu/Torralba	Ittireddu, Mores, Ozieri, Torralba, Tula	30	165-315	Stream pools, lentic waters, artificial barrage	Arrigoni (2006-2015), 3 sites	Currently occurring	26 A, 4 P
Nymphaea alba	Native	Coghinas River	Riu de Crasta	Monti	5	240-472	Stream pools, artificial lake	New record (this study)	Currently occurring	A
Nymphaea alba	Native	Coghinas River	Riu Rizzolu	Ozieri	9	182-198	Stream pools	New record (this study)	Currently occurring	4 A, 5 P
Nymphaea alba	Native	Posada River	Rio Posada	Alà dei Sardi, Bitti, Lodè, Padru	4	53-199	Stream pools	Orrù *et al.* (2020), 1 site	Currently occurring	P
Nymphaea alba	Native	Posada River	Riu S'Aragone	Alà dei Sardi	1	247	Stream pool	New record (this study)	Currently occurring	P
Nymphaea alba	Native	Posada River	Rio Altana	Alà dei Sardi, Bitti	4	456-665	Stream pools, artificial lake	New record (this study)	Currently occurring	P
Nymphaea alba	Native	Posada River	Rio Neulavè	Padru	3	324-538	Stream pools	New record (this study)	Currently occurring	A
Nymphaea alba	Native	Rio Barca	Rio Barca	Alghero	3	7-26	Stream pools	Arrigoni (2006-2015), unspecified site	Currently occurring	A
Nymphaea alba	Native	Temo River	Temo River	Bosa, Cossoine, Padria, Romana	30	12-164	Stream pools	Arrigoni (2006-2015), 1 site	Currently occurring	11 A, 19 P
Nymphaea alba	Native	Temo River	Rio Sa Entale	Bosa	4	123-132	Stream pools	New record (this study)	Currently occurring	P

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Tab 1. Continued from previous page.

Taxon	Status unit	Hydrographic	Site	Municipality	N. of sites	Elevation (m asl)	Habitat	First record	Local persistence	Protected areas (A/P)
Nymphaea alba	Native	Temo River	Monte Minerva	Villanova Monteleone	1	340	Artificial lake	ItaliaIsWet (Fois *et al.*, 2022)	Currently occurring	P
Nymphaea alba	Native	Cedrino River	Cedrino	Dorgali	1	160	Stream pool	New record (this study, not confirmed)	Not confirmed (likely extinct)	A
Nymphaea alba	Native	Riu Mannu of Decimomannu	Riu Mannu of Decimomannu	Decimomannu	1	35	Stream pool	Moris (1837-1859)	Currently occurring	A
Nymphaea alba	Native	Riu Mannu of Decimomannu	Ex case Laterizi lakes	Assemini	1	0	Artificial lake	New record (this study, not confirmed)	Locally extinct	A
Nymphaea alba	Native	Cixerri River	Cixerri	Siliqua	3	57-71	Secondary riverbed, artificial lake	Moris (1837-1859)	Currently occurring	A
Nymphaea alba	Native	Paringiano	Paringiano	Carbonia	1	17	Stream pool	New record (this study, not confirmed)	Locally extinct	A
Nymphaea alba	Native	Tirso River	Tirso	Oristano	1	6	River	Mola (1919)	Locally extinct	A
Nymphaea alba	Native	Rio Santa Lucia	Tanca di Nissa	Capoterra	1	2	River mouth	De Martis *et al.* (1984)	Locally extinct	A
Nuphar lutea	Native	Coghinas River	Riu of Berchidda	Berchidda	6	183-200	Lentic waters	New record (this study)	Currently occurring	A
Nuphar lutea	Native	Coghinas River	Riu Mannu of Berchidda	Berchidda, Oschiri	4	170-173	Lentic waters	Arrigoni (2006-2015)	Currently occurring	2 A, 2 P
Nuphar lutea	Native	Coghinas River	Riu Mannu of Oschiri	Oschiri	1	n.a.	Lentic waters	Mola (1919)	Locally extinct	A
Nuphar lutea	Native	Coghinas River	Riu Mannu of Ozieri/Mores Ittireddu	Ittireddu, Mores, Ozieri	8	191-245	Lentic waters	Moris (1827)	Currently occurring	3 A, 5 P
Nuphar lutea	Native	Coghinas River	Coghinas River	Bortigiadas, Erula, Oschiri, Tula	18	58-95	Lentic waters	New record (this study)	Currently occurring	A
Nuphar lutea	Native	Rio San Girolamo	Poggio dei Pini	Capoterra	1	62	Artificial lake	Bacchetta (2006)	Locally extinct	A
Nuphar lutea	Native	Cixerri River	San Genesio	Assemini	1	1	Channel	Ruggero *et al.* (2024)	Locally extinct	A
Nymphoides peltata	Native	Rio Mare Foghe	Rio Mare Foghe	Riola Sardo	1	6	River	Moris (1827)	Known only from historical records	A
Nelumbo nucifera	Alien (casual)	Rio Mare Foghe	Ex purification plant	Baratili San Pietro	1	7	Artificial pool	Conti *et al.* (2005)	Locally extinct	A
Nymphaea mexicana	Alien (naturalized)	Coghinas River	Sculpture park Funtanazza	Chiaramonti	1	342	Artificial lake	New record (this study)	Currently occurring	A
Nymphaea × *marliacea*	Alien (casual)	Coghinas River	Li Sciucchi	Berchidda	1	990	Artificial lake	Desfayes (2008)	Currently occurring	P
Nymphaea × *marliacea*	Alien (naturalized)	Posada River	Sos Sonorcolos	Alà dei Sardi	1	657	Artificial lake	New record (this study)	Currently occurring	A
Nymphaea × *marliacea*	Alien (naturalized)	Cedrino River	Near Agriturismo Didone	Dorgali	1	208	Artificial lake	New record (this study)	Currently occurring	A
Nymphaea × *marliacea*	Alien (naturalized)	Rio Leonaxiu	Torre Sant'Isidoro	Teulada	1	8	Artificial lake	ItaliaIsWet (Fois *et al.*, 2022)	Currently occurring	A

In South Sardinia, another small population, probably adventive, was recorded by Ruggero *et al.* (2024) near Assemini (CA). However, recent searches did not allow to confirm its occurrence, suggesting a casual appearance (Tab. 1).

Nymphaea alba L. (Nymphaeaceae)

Historical data: The older records of *Nymphaea alba* mostly concerned southern Sardinia. Specifically, Moris (1837-1859) reported Tanca di Nizza (Capoterra, CA), Monastir (CA), Siliqua (CA, herbarium specimen collected by Dore in 1864, CAG!). Casu collected an herbarium specimen in 1910 near Santa Gilla Lagoon, and mouths of the Rio Mannu and Cixerri (Assemini, CA - preserved in SASSA - cited by De Martis *et al.*, 1984). Mola (1919) found it on Tirso River, near Oristano. Many of these records were not later confirmed. Arrigoni (2006-2015) reported the species mostly from literature, but adding streams of Mores, Ozieri, Oschiri, Bosa and Alghero. Subsequently, Desfayes (2008) added a site along Liscia River, and Orrù *et al.* (2020) a site along Rio Posada.

Current distribution: In Sardinia, we recorded the species in 173 different sites, distributed across 17 hydrographic basins and 27 waterbodies, and a few artificial small basins, from sea level to 650 m asl (Tab. 1).

North-eastern Sardinia is the richest part of the island both in number of sites and river basins, with nine hydrographic basins,18 waterbodies and 161 sites. Among them, in the Rio Pirastru (Trinità d'Agultu), a record of *N. candida* by Castiglia was reported as doubtful by Arrigoni (2006-2015). Here, we definitely exclude it since the plants observed on that stream belong to *N. alba*.

In the north-western side, the species occurs in two different river basins and three waterbodies (Fig. 1; Tab. 1).

In central eastern Sardinia, a single site was discovered in a small stream between Oliena and Dorgali (NU), not found again after the flood of 2013 (Fig. 1; Tab.1). The ancient record from Oristano is to be considered extinct.

In South Sardinia, we only provide partial confirmation since *N. alba* is very rare, while most of sites are now locally extinct (Fig. 1; Tab. 1). Specifically, all the previous records from Assemini, Capoterra, Monastir, have no received confirmation as well as some of our findings.

Nymphoides peltata (S.G.Gmel.) Kuntze (Menyanthaceae)

Historical data: Only one record of this species exists from Sardinia, dating back to Moris (1827), who reported it near Riola Sardo (OR; Fig. 1; Tab. 1). No further records have been obtained, and the species was not confirmed by subsequent authors (e.g., Corbetta and Lorenzoni, 1976; Fenu and Bacchetta, 2008), nor by other researchers or by the present surveys.

Current distribution: Given the lack of confirmed records for nearly two centuries, the species is to be considered extinct in Sardinia (Tab. 1).

Alien taxa

Nelumbo nucifera Gaertn. (Nelumbonaceae)

Historical data: The occurrence of this alien species in Sardinia was not defined under any status by Galasso *et al.* (2024) and was based on reports from Conti *et al.* (2005) and the project EPIDEMIE (Hulme, 2003).

Current distribution: A few individuals of this species were personally observed by the authors in 2008 within a dismissed experimental site consisting of some small artificial pools, previously used for phytoremediation and not directly connected with waterbodies, located on the outskirts of Baratili San Pietro (OR). These plants survived in poor conditions together with other non-native macrophytes. No further observations have been made since then. Recent surveys at the site did not detect the species and indicated that the current site conditions (i.e. desiccation of the artificial pools and invasion by *Arundo donax* L.) are unsuitable for its persistence. Therefore, the species is currently excluded from the alien flora of Sardinia (Tab. 1).

Nymphaea mexicana Zucc. (Nymphaeaceae)

Historical data: The species was first reported in Sardinia by Puddu *et al.* (2016), although without any geographic reference, then considered naturalized by Galasso *et al.* (2024).

Current distribution: In Sardinia, the species occurs in a small artificial lake open to the public, near Chiaramonti (SS), where it was intentionally introduced for ornamental purposes and subsequently reproduced and spread within that basin (Fig. 1; Tab. 1). In this small basin (approximately 2,700 m^2), the species currently occupiers several patches, covering a total area of about 200 m^2.

Nymphaea × *marliacea* Lat.-Marl. (Nymphaeaceae)

Historical data: This hybrid taxon is cultivated for ornamental purposes and has locally escaped cultivation in areas adjacent to where it was planted. A first record was made on Mount Limbara (Desfayes, 2008) under *N. alba*, a taxonomic treatment later corrected by Calvia and Ruggero (2020). At that site, a single plant grows from at least 1999 but never showing evidence of sexual reproduction, being therefore regarded as casual alien (Calvia and Ruggero, 2023).

Current distribution: The taxon is currently known from some artificial basins across the island (Fig. 1, Tab. 1). The most consistent population is located in the municipality of Teulada (SU) and was also recorded in the ItaliaIsWet database (Fois *et al.*, 2022). In October 2025, the taxon occupied approximately 1,700 m^2 of a total lake surface of 8,550 m^2.

DISCUSSION

This study confirms the current occurrence of four nymphaeid taxa in Sardinia, including two native species (*Nymphaea alba* and *Nuphar lutea*) and two alien taxa (*Nymphaea mexicana* and *N.* × *marliacea*). Conversely, two additional taxa previously reported from the island, the native *Nymphoides peltata* and the alien *Nelumbo nucifera*, remain unconfirmed at present, highlighting the importance of reassessing historical and poorly documented records.

Current distribution and ecology of waterlilies in Sardinia

The distribution of the two native species is well defined, with *Nymphaea alba* occurring across a large part of Sardinia, although it is more abundant in the northern half. The few populations found in South Sardinia, after more than a century without new records, can be interpreted as relic occurrences and still undergoing significant decline.

Overall, *N. alba* exhibits the highest degree of environmental versatility, often occurring in stream habitats where it is adapted to clear, oligotrophic waters with silicate, sandy, and granitic substrates (Heslop-Harrison, 1955). In valley bottoms, however, it sometimes shows a preference for stagnant ponds and remnant pools of abandoned riverbeds, tending to disappear from the main channels, which are often straightened and embanked. At least in the Coghinas basin, in lowland areas it is largely or entirely replaced by *N. lutea*, which is known to be more competitive under such conditions (Temmink *et al.*, 2021; Dalla Vecchia *et al.*, 2024).

Interestingly, in various cases *N. alba* occurs in streams with relatively fast flow, despite the assumption that this species is typical of lentic waters (Klok and Velde, 2017; Pignatti, 2017). More rarely, *N. alba* inhabits permanent lentic environments such as river mouths (Liscia River, Rio Li Cossi), astatic ponds (Rio San Giovanni, Riu Mannu of Decimomannu), and even artificial basins (Alà dei Sardi, OT; Assemini).

In contrast, the distribution of *Nuphar lutea* is restricted exclusively to the northern areas, while records from southern Sardinia are not confirmed here. Specifically, Sardinian populations of *N. lutea* are primarily associated with inner valley-bottom environments characterized by deeper, nutrient-rich soils and generally slow-flowing waters. In these settings, it often forms extensive populations, occupying several hundred squared meters (Temmink *et al.*, 2021), whereas *N. alba* generally tends to form more localized stands.

In both species, the phases of emergence, flowering, and fruiting normally coincide with the seasonal drawdown and subsequent drying of Mediterranean watercourses, persisting only in permanent or semi-permanent pools and natural ponds (Hershkovitz and Gasith, 2013). Nevertheless, the rhizomes and submerged leaves, particularly of *N. alba*, must withstand strong currents during the winter months, when precipitation swells the waterbodies. During extreme events, these conditions have proved particularly challenging, with local metapopulations being swept away by catastrophic occurrences such as the 2013 flood (Righini *et al.*, 2017).

From a synecological perspective, the two native species tend to form monospecific stands or, alternatively, associate with a few submerged (e.g., *Ceratophyllum demersum* L., *Myriophyllum spicatum* L., *Zannichellia palustris* L.), floating (e.g., *Potamogeton natans* L., *P. coloratus* Hornem., *Utricularia australis* R.Br.), and pleustophytic (*Lemna* spp.) hydrophytes, forming low-diversity communities mainly attributable to the alliance *Nymphaeion albae* Oberd. 1957, order *Potamogetonetalia* Koch 1926 of the class *Potamogetonetea* Klika in Klika and Novák 1941. A large proportion of these communities, found in lentic or slow-flowing aquatic environments, are of conservation interest, as they largely correspond to the habitat type 3150 "Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition*" listed in Directive 92/43/EEC (Biondi *et al.*, 2010).

Regarding the alien taxa, their distribution patterns in Sardinia raise questions about the extent of their naturalization on the island. Some Nymphaeaceae exhibit several limitations in seed dispersal due to early desiccation and seed digestion (Smits *et al.*, 1989), while others primarily rely on asexual propagation through stolons or horizontal rhizomes (Wiersema, 1988). These constraints highlight the importance of continuous waterbodies for dispersal, both via seeds and vegetative fragments (hydrochory). Therefore, the limited potential for spread beyond the closed basins where these taxa are currently confined appears to be a key factor for restricting the diffusion of alien Nymphaeaceae in Sardinia. This is noteworthy, considering the adaptability and capacity of *N. mexicana* to colonize new environments beyond its native range (Nzei *et al.*, 2024).

Threats and pressures

The apparent abundance of localities, for both native *Nymphaea* species should not be misleading, as both taxa show evidence of decline across various watercourses. This decline results from factors such as alterations in the hydrological regime, flood events, excessive deposition of river sediments (Greenway, 2012; Sabater *et al.*, 2023), and the presence of invasive alien species.

In particular, waterlilies are part of the diet of *Myocastor coypus* Molina, as previously detected in other parts of Europe (Laurie, 1946; Prigioni *et al.*, 2005; Casini *et al.*, 2007). Without preventive control measures, a growing coypu population may exert increasing pressure on waterlily populations, as it has already been documented for *Nuphar lutea* (Bertolino *et al.*, 2005).

Moreover, in areas that have experienced a rapid spread of *Procambarus clarkii* Girard in recent decades, a concurrent reduction of waterlily populations has been recorded (Smart *et al.*, 2002; Lodge *et al.*, 2005). The simultaneous invasion of these two species could have contributed to the disappearance and severe decline of waterlilies from several sites in southern Sardinia.

Additionally, due to the expansion of alien taxa within the genus *Nymphaea*, there is the potential risk of pollen-mediated gene flow and genetic pollution between cultivated and/or naturalized taxa, which have been shown to cause declines in *N. alba* populations elsewhere (Yakandawala and Yakandawala, 2011; Nierbauer *et al.*, 2014). In particular, *N.* × *marliacea* on Limbara and Alà dei Sardi artificial lakes occurs only a few kilometers far from native populations and deserves attention from a conservation perspective.

Another significant factor that has affected and is expected to further deteriorate the conditions of riverbeds colonized by nymphaeid communities is climate change. Pools along many Sardinian streams and intermittent rivers are experiencing increasingly severe summer droughts (Rhazi and Grillas, 2010), which often persist for long periods and expose the plants' rhizomes to open air. However, extreme flooding events, such as those that occurred in northern and central-eastern Sardinia in November 2013, can profoundly alter riverbed morphology and species richness (Talbot *et al.*, 2018), locally extinguishing nymphaeid populations to varying degrees. The 2013 event, for example, drastically reduced the number of *N. alba* metapopulations along the Rio Posada, Rio S'Eleme (Coghinas River basin), and in the lower reach of the Liscia River, further compromising previously existing stands, which have since been strongly diminished.

Nonetheless, human-induced modifications of riverbeds remain the primary drivers of local extinction (Nzei *et al.*, 2022). This is particularly evident in southern Sardinia, especially along the main stretches of the Cixerri and Mannu rivers, which have undergone significant straightening, channelization, and diversion from their original courses. For instance, historical photographs taken in 1948 by Wolf Suschitzky, preserved in the Suschitzky Fund within the *Istituto Etnografico della Sardegna* (isresardegna.org), document rich populations of *N. alba* along the Riu Mannu of Siliqua. The species, once considered extinct in this area, is currently confined to a few remnant sites.

In North Sardinia, several populations were almost certainly depleted by dam construction. In at least three cases (Lake Coghinas, Posada, and Temo) there is evidence of fragmentation or complete loss of formerly continuous populations, supporting the interpretation of dams as local drivers of eradication (Jones *et al.*, 2020).

Notably, the construction of the Coghinas dam in 1926 led to the submersion of extensive river stretches that almost certainly hosted waterlily populations. The resulting lake now extends for nearly 30 linear kilometers of former river shorelines, allowing to estimate that the dam caused a reduction in suitable habitats amounting to approximately one-third of the former *Nuphar lutea* populations of Sardinia. Specifically, the old course of the Riu Mannu of Oschiri once flowed through the area now occupied by the lake, suggesting that the population recorded by Mola (1919) no longer exists. Furthermore, dam construction caused the isolation of growing stations downstream of the reservoir.

Finally, it cannot be ruled out that the channelization and modification of Tirso River and adjacent watercourses could have contributed to the local extinction of *N. alba* and that of *Nymphoides peltata* in Sardinia.

Moreover, we stated that the presence of *Nymphaea alba* within protected areas is quite limited, being recorded in only six among Special Areas of Conservation (SACs), Special Protection Areas (SPAs) and regional parks. In contrast, most of its populations grow in streams or river stretches lacking any legal protection and are at constant risk of habitat alterations through dam constructions, channelization, or pollution. The same applies to the even rarer *N. lutea*, of which only seven of the 38 known recorded sites fall within a protected area, and one population is already extinct.

Several insular populations of both species are undergoing local decline, primarily due to anthropogenic pressures that directly or indirectly alter the environmental conditions essential for their persistence, but also as a consequence of extreme events and the spread of alien species. Such processes represent a concrete threat to the conservation of these native taxa and to the related plant communities in which they occur as diagnostic or characteristic species. To safeguard these taxa and the ecologically valuable communities they form, targeted in situ and ex situ conservation actions should be considered to prevent further local extinctions. Measures such as maintaining living specimens in botanical gardens and preserving germplasm in seed banks should be prioritized. Furthermore, the watercourses hosting these species should be evaluated for the establishment of new protected areas, as they support several habitats and species of community interest and of biogeographic value, such as *Butomus umbellatus* L., *Carex panormitana* Guss., *Cladium mariscus* (L.) Pohl, *Spiranthes aestivalis* (Poir.) Rich., *etc*. In this regard, greater awareness among policy makers and local authorities is advisable.

CONCLUSIONS

The findings of this study provide an updated assessment of nymphaeids in Sardinia, contributing to the floristic and chorological knowledge of the island, particularly concerning aquatic macrophytes, emblematic representatives of freshwater wetlands, which rank among the most globally threatened ecosystems.

Two native species, *Nymphaea alba* and *Nuphar lutea*, occur in restricted areas of Sardinia, while *Nymphoides peltata* is currently extinct on the island. *N. alba* is mainly distributed in the northern and central sectors, with only scattered occurrences in the South.

Regarding alien taxa, due to the absence of data over the past 15 years, *Nelumbo nucifera* is here reported as no longer present on the island. The naturalized taxa *Nymphaea mexicana* and *N.* × *marliacea* are currently confined to artificial environments, and the removal of individuals growing near native populations is recommended as a precautionary measure.

The results of this work significantly reduce long-standing uncertainties and address gaps in floristic knowledge, providing an updated and verified account of the distribution and status of nymphaeids in Sardinia, and offering a reliable basis for future monitoring and conservation of native taxa and their associated habitats, as well as for the management of alien species.

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