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ALIEN FLORA IN FRESHWATER ECOSYSTEMS: BASIC KNOWLEDGE FOR MITIGATING THREATS TO NATIVE BIODIVERSITY IN LAZIO REGION (CENTRAL ITALY)

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Abstract – Freshwater ecosystems are among the most biologically diverse on Earth providing essential ecosystem services for nature and society. Human impacts on lakes, rivers, streams, wetlands, and associated riparian habitats are dramatically reducing biodiversity and robbing critical natural resources and services. Degradation of freshwater ecosystems is more rapid than that of terrestrial ones. Main anthropogenic threats include pollution, land-use change, and biological invasions. Regarding biological invasions, one of the main drivers of biodiversity loss at the global level, the listing of floristic diversity represents a fundamental step to help manage non-native species.

Here we present the list of aliens occurring in freshwater ecosystems of Lazio region (central Italy) and their characterization. The list includes 118 taxa (11.9% of the alien regional flora), belonging to 89 genera and 49 families. Richest families are Asteraceae (18 taxa; 15.2%) and Poaceae (10 taxa; 8.5%); richest genera are *Amaranthus*, *Cyperus*, *Euphorbia*, *Oenothera*, *Symphyotrichum*. Eleven taxa are listed among the worst European alien species. Therophytes, which usually suggest xeric conditions, are highly represented (30 taxa; 28.8%), highlighting their capability of adapting to diverse environmental conditions. The high proportion of taxa with a wide distribution (28 taxa; 23.7%) reveals the occurrence of r-selected species; 38 taxa (33.2%), native to the Americas, confirm the high migration and commercial flows between New and Old Worlds. Several taxa occur in more than one habitat (aquatic, riparian, humid), with aquatic habitats including the highest percentage of invasive taxa (27.3%). Most invasive species are: *Alternanthera philoxeroides*, *Lemna minuta*, *Ludwigia peploides*, *Pontederia crassipes* (free-floating macrophytes) and *Arundo donax* and *Robinia pseudoacacia* (terrestrial species). The number of invasive species decreases with inundation rates, whereas casual aliens increase. The analysis of Hydroecological regions shows a high percentage (33.3%) of invasive taxa in HER13 ("Appennino Centrale"), probably due to the occurrence of industrial sites in the Sacco river valley (southern Lazio).

Keywords: biodiversity, biological form, chorotype element, hydroecoregions, invasive species, status of naturalization.

Introduction

Plant invasion is a global phenomenon associated with human-mediated transportation of non-native plants beyond their native distribution ranges (Seebens et al., 2021; Gloria et al., 2023). During the last few centuries, the number of alien species increased in many taxonomic groups, mainly due to trade, transport, and land-use change (Hulme, 2009; Pauchard & Alaback, 2004). Biological invasions are considered the fifth main driver of biodiversity loss at the global level, especially due to naturalized and invasive aliens, which respectively include about 14000 and 2500 taxa at the global scale (Bhatta et al., 2023). These aliens are one of the most significant causes of ecosystem disruption (the so-called ecological impact) but are also responsible for economic (e.g. reduction of agricultural productivity; Matzrafi et al., 2023) and social impacts (e.g. allergenicity; Pecoraro et al., 2024).

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Freshwater ecosystems (embracing streams, rivers, lakes, riparian areas, and other wetlands) represent key hotspots for biodiversity and, at the same time, are one of the most impacted natural systems worldwide due to human activities and climate change (Reid et al., 2019; Bolpagni, 2021; Polce et al., 2023). Especially, vulnerability to human activities is related to the behaviour of inland waters as filters and acceptors for effluents (Severini et al., 2020), which in turn facilitates physico-chemical perturbations, generated and exerted on the catchment scale, and spread of alien species (Bolpagni, 2021).
In this context, many countries have established laws and regulations to safeguard freshwater ecosystems, including the designation of protected areas, setting of water quality standards, and implementing measures to control pollution and habitat destruction. At the international level, protection tools include the UN *Ramsar Convention on Wetlands* (1971) and, in the European Union, the *Habitats Directive* (92/43/EEC), the *Birds Directive* (79/409/EEC), and the *Water Framework Directive* (2000/60/EC, focused on ensuring good qualitative and quantitative health, i.e. on reducing and removing pollution and on ensuring that there is enough water to support wildlife and human needs).
As part of the ongoing studies on the flora of Italy, with a special focus on Lazio region (central Italy; e.g., Celesti-Grapow et al., 2013; Iberite & Pelliccioni, 2010; Iberite & Iamonico, 2015; Iberite et al., 2015, 2017; Iamonico et al., 2014, 2020, 2022a; Di Pietro et al., 2022; Iamonico, 2022; Sciuto et al., 2023), we present the list of the alien species occurring in freshwater ecosystems, providing an overview from various point of views (status of naturalization, biological forms, and chorotypes).

MATERIAL AND METHODS

The floristic list of alien taxa occurring in freshwater ecosystems of Lazio region was first extracted from a comprehensive work on the vascular flora (Anzalone et al., 2010) and from the regional atlas of the alien flora (Lucchese, 2017). In turn, these sources are based on all previously published literature along with field collections made by the authors themselves. For more updated information, a further check of published literature from 2017 to 2024 was carried out and additional floristic records were added, i.e. from Iamonico (2015, 2021, 2022), Stinca et al. (2021), Iamonico et al. (2022b), Iamonico & Nicolella (2023, 2024). As regards the flora by Anzalone et al. (2010), we considered all the aliens occurring at least in one of the following habitats (the name originally adopted by the authors is in brackets): marshland ("acquitr." = acquitrini), tributary ("affl." = affluente), clayey ("argill." = argilloso), river ("F." = fiume), canal ("F.so" = fosso), stream ("torr." = torrente), banks ("sponde"), humid environments ("amb. umidi" = ambienti umidi), humid forests ("boschi umidi"), pebbly riverbeds ("greti"), humid uncultivated lands ("incolti umidi"), and riverbanks ("rive"). As regard the flora by Lucchese (2017), since no habitat was clearly specified, we referred to the localities in which the species were recorded [e.g., *Ipomoea purpurea* (L.) Roth was considered as a riparian species since it was indicated along the banks of Tiber River]. All these habitats were therefore arranged into five zones, according to dominant fluvial dynamic processes as proposed by Dufour & Rodríguez-González (2019), and thus into three main macro-habitats, i.e. aquatic, riparian, and humid (Tab. 1).

Table 1. Macro-habitats of occurrence adopted in the present study (last row of the table) based on the zones proposed by Dufour & Rodríguez-González (2019) and respective ecological/biological features.

	Zone 5	Zone 4	Zone 3	Zone 2	Zone 1
Water occurrence	Permanently inundated	Frequently inundated	Regularly inundated	Occasionally inundated	Rarely inundated; inundation absent
Sediments	High sediment dynamics	High sediment dynamics	Significant sediment deposition	No significant sediment dynamics	No sediment dynamics
Plants ecology	Aquatic plants tolerant of permanent inundation and burial	Emergent aquatic and riparian plants tolerant of frequent inundation and burial	Riparian plants tolerant of regular inundation and moderate sedimentation	Riparian plants with vary inundation tolerance	Plants tolerant to soil moisture or alluvial groundwater regime
Biological form	Hydrophytes	Helophytes	Phanerophytes	Phanerophytes	Geophytes, Therophytes
Macro-habitat type	Aquatic	Aquatic	Riparian	Riparian	Humid

Suddenly, each taxon (the nomenclature follows the *Portal of the Flora of Italy*; PFI 2024) was associated with a biological form and chorotype according to Pignatti et al. [2017-2019; chorotypes where reclassified according to Iamonico (2022)], and with the status of naturalization in the region according to Anzalone et al. (2010) and Lucchese (2017).
Concerning the habitat, we firstly considered the proposal by Dufour & Rodríguez-González (2019) who classified plants along rivers into five zones based on the dominant fluvial dynamic processes. Based on these five zones, we classified three habitats, i.e. aquatic, riparian, and humid (Tab. 1).
Finally, we analyzed the occurrence of alien species with respect to the hydroecoregions (HERs), i.e. geographic areas with a narrow variability in chemical, physical and biological features of water courses and adopted by the European Member States for the implementation of the *Water Framework Directive* (Wasson et al., 2006). A GIS approach [overlapping of layers of HERs and Province boundaries of Lazio region (Wasson et al., 2006)] was used.

Results and discussion

The list of alien plants occurring in freshwater ecosystems of Lazio region includes 118 taxa [corresponding to 11.9% of the total alien regional flora (539 taxa according to Galasso et al., 2024)], belonging to 89 genera and 49 families. Four taxa belong to Monilophyta [*Azolla filiculoides* Lam., *Cyrtomium falcatum* (L.f.) C.Presl, *Nephrolepis cordifolia* (L.) C.Presl, and *Salvinia molesta* D.S.Mitch.], whereas the remaining 114 are Angiosperms (Gymnosperms are lacking). The richest families are Asteraceae Bercht. & J.Presl (18 taxa, corresponding to 15.2% of the flora) and Poaceae Barnhart (10; 8.5%); 24 families comprise between 2 and 5 taxa, whereas 23 families include one taxon each. The richest genera are *Amaranthus* L., *Cyperus* L., *Euphorbia* L., *Oenothera* L., and *Symphyotrichum* Nees (3 taxa each); 18 genera comprise 2 taxa each, whereas 66 genera are monospecific. To be noted that 11 taxa (marked with an asterisk in the following list) are included in the list of the worst alien species in Europe (Nentwig et al., 2018).

MONILOPHYTA
DRYOPTERIDACEAE
Cyrtomium falcatum (L.f.) C.Presl, H ros, East Asian, CAS

NEPHROLEPIDACEAE
Nephrolepis cordifolia (L.) C.Presl, G rhiz, Tropical, CAS

*SALVINIACEAE
Azolla filiculoides Lam., I nat, Tropical, NAT
Salvinia molesta D.S.Mitch., I nat, Wide distribution, CAS

ANGIOSPERMAE
ACANTHACEAE
Ruellia simplex C.Wright, NP, American, CAS

AMARANTHACEAE
**Alternanthera philoxeroides* (Mart.) Griseb., I rad, South American, NAT
Amaranthus blitoides S.Watson, T scap, North American, INV
Amaranthus hybridus L. subsp. *hypochondriacus* (L.) Thell., T scap, U.S.A. and Mexico, NAT
Amaranthus retroflexus L., T scap, North American, INV
Beta vulgaris L. subsp. *vulgaris*, H scap, Eurimediterranean, CAS
Dysphania ambrosioides (L.) Mosyakin & Clemants, H scap, Tropical, INV

APIACEAE
Apium graveolens L., H scap, Mediterranean, NAT
Coriandrum sativum L., T scap, South-Western Mediterranean, CAS

APOCYNACEAE
Nerium oleander L. subsp. *oleander*, P caesp-P scap, Stenomediterranean, CAS
Trachelospermum jasminoides (Lindl.) Lem., P lian, Asian, CAS

ARACEAE
Colocasia esculenta (L.) Schott, G rhiz, Asian, NAT
Lemna minuta Kunth, I nat, Tropical, INV
Lemna valdiviana Phil., I nat, American, CAS
Wolffia arrhiza (L.) Horkel ex Wimm., I nat, Tropical, CAS
Zantedeschia aethiopica (L.) Spreng., G rhiz, African, NAT

ARALIACEAE
**Hydrocotyle ranunculoides* L.f., I nat, Tropical, NAT

ASPARAGACEAE
Asparagus officinalis L. subsp. *officinalis*, G rhiz, Eurimediterranean, CAS
Chlorophytum comosum (Thumbs.) Jacques, H scap, African, CAS

ASTERACEAE
Artemisia annua L., T scap , Eurasian, NAT
Artemisia verlotiorum Lamotte, G rhiz, East Asian, INV
Bidens aurea (Aiton) Sherff, H scap, American, CAS

Bidens frondosa L., T scap, North American, INV
Cotula coronopifolia L., T scap, African, NAT
Delairea odorata Lem., Ch frut, South African, CAS
Eclipta prostrata (L.) L, T scap, Tropical, CAS
Erigeron annuus (L.) Desf. subsp. *annuus*, T scap, North American, NAT
Erigeron karvinskianus DC., H scap, Tropical, NAT
Guizotia abyssinica (L.f.) Cass., T scap, African, CAS
Helianthus tuberosus L., G bulb, North American, INV
Inula helenium L., H scap, Orophile-South-East-European, CAS
Senecio inaequidens DC., T scap, African, INV
Symphyotrichum lanceolatum (Willd.) G.L.Nesom, H scap, North American, CAS
Symphyotrichum novi-belgii (L.) G.L.Nesom, H scap, North American, CAS
Symphyotrichum squamatum (Spreng.) G.L.Nesom, H scap, Tropical, INV
Tripleurospermum inodorum (L.) Sch.Bip., H bienn, European, CAS
Xanthium orientale L., T scap, American, INV

BALSAMINACEAE
Impatiens balfourii Hook.f., H scap, Asian, CAS
Impatiens parviflora DC., T scap, East Asian, NAT

BRASSICACEAE
Armoracia rusticana G.Gaertn., B.Mey. & Scherb., G rhiz, Est European, CAS
Brassica nigra (L.) W.D.J.Koch, T scap, Eurimediterranean, CAS
Rorippa austriaca (Crantz) Besser, H scap, Pontic, NAT

CANNABACEAE
Cannabis sativa L., T scap, Asian, CAS

CANNACEAE
Canna indica L., G rhiz, Tropical, CAS

CAPRIOFOLIACEAE
Lonicera japonica Thunb., P lian, East Asian, NAT

CLEOMACEAE
Polanisia dodecandra (L.) DC. subsp. *trachysperma* (Torr. & A.Gray) Iltis, T scap, North American, CAS

CONVOLVULACEAE
Ipomoea indica (Burm.) Merr., G rhiz, Tropical, NAT
Ipomoea purpurea (L.) Roth, T scap, Tropical, CAS

CUCURBITACEAE
Cucurbita maxima Duchesne subsp. *maxima,* T scap, American, CAS
Sicyos angulatus L., T scap, North American, CAS

CYPERACEAE
Cyperus alternifolius L. subsp. *flabelliformis* Kük., H caesp, Tropical, CAS
Cyperus eragrostis Lam., G rhiz , Tropical, CAS
Cyperus esculentus L., He, Tropical, NAT

EBENACEAE
Diospyros kaki Thunb., P scap, Western Asian, CAS
Diospyros lotus L. , P scap, Asian, CAS

EUPHORBIACEAE
Euphorbia humifusa Willd., T rept, Asian, NAT
Euphorbia nutans Lag., T scap, North American, NAT
Euphorbia pulcherrima Willd. ex Klotzsch, NP, Central American, CAS

FABACEAE
**Acacia dealbata* Link, P scap, Australian, NAT
Amorpha fruticosa L., P caesp, North American, NAT
**Robinia pseudoacacia* L., P scap-P caesp, North American, INV

HALORAGACEAE
Myriophyllum aquaticum (Vell.) Verdc., I rad, South American, NAT
HYDRANGEACEAE
Hydrangea macrophylla (Thunb.) Ser., NP, East Asian, NAT

HYDROCHARITACEAE
Elodea canadensis Michx., I rad, North American, INV

JUGLANDACEAE
Carya illinoinensis (Wangenh.) K.Koch, P scap, North American and Mexican, CAS

LAMIACEAE
Melissa officinalis L. subsp. *officinalis*, H scap, West Asian, NAT

LINDERNIACEAE
Lindernia dubia (L.) Pennell, T scap, North American, NAT

LYTHRACEAE
Punica granatum L., P scap, West Asian, NAT

MALVACEAE
Abutilon theophrasti Medik., T scap, Pontic, NAT
Hibiscus moscheutos L. subsp. *moscheutos*, H scap, Circumboreal, CAS

Hibiscus trionum L., T scap, Tropical, CAS

MORACEAE
Morus alba L., P scap, East Asian, CAS
Morus nigra L., P scap, West Asian, CAS

MYRTACEAE
**Eucalyptus camaldulensis* Dehnh. subsp. *camaldulensis*, P scap, Australian, CAS
**Eucalyptus globulus* Labill. subsp. *globulus*, P scap, Australian, CAS
Melaleuca williamsii Craven subsp. *synoriensis* Craven, P caesp, Australian, CAS

NELUMBONACEAE
Nelumbo nucifera Gaertn., I rad, Paleotropical, NAT

ONAGRACEAE
**Ludwigia peploides* (Kunth) P.H.Raven subsp. *montevidensis* (Spreng.) P.H.Raven, H caesp, American, NAT
Oenothera glazioviana Micheli, H bienn, European, NAT
Oenothera rosea L'Hér. ex Aiton, H bienn, South American, CAS
Oenothera stricta Ledeb. ex Link subsp. *stricta,* H bienn, South American, CAS

PHYTOLACCACEAE
Phytolacca americana L., G rhiz, North American, INV
PLATANACEAE
Platanus hispanica Mill. ex Münchh., P scap, Eurimediterranean, NAT
Platanus orientalis L., P scap, Sud-Est European, NAT

POACEAE
**Arundo donax* L., G rhiz, Sub Wide distribution, INV
Echinochloa colona (L.) Link subsp. *colona*, T scap, Tropical, CAS
Dactyloctenium aegyptium (L.) Willd., T scap, Tropical, NAT
Panicum capillare L., T scap, North American, CAS
Panicum dichotomiflorum Michx., T scap, North American, CAS
Paspalum distichum L., G rhiz, Wide distribution, INV
Phyllostachys reticulata (Rupr.) K.Koch, P scap, West Asian, CAS
Setaria adhaerens (Forssk.) Chiov., T scap, Tropical, CAS
Setaria parviflora (Poir.) Kerguélen, H caesp, South American, NAT
Zea mays L. subsp. *mays*, T scap, Tropical, NAT

POLYGONACEAE
Fallopia baldschuanica (Regel) Holub, P lian, Eurasian, CAS

PONTEDERIACEAE
**Pontederia crassipes* Mart., I nat, Tropical, INV

ROSACEAE
Prunus cerasifera Ehrh., P scap-P caesp, Pontic, NAT
Prunus persica (L.) Batsch, P scap-P caesp, East Asian, CAS

SALICACEAE
Populus ×canadensis Moench, P scap, North American, NAT
Salix babylonica L., P scap, Tropical, CAS
Salix ×fragilis L., P scap-P caesp, Eurosiberian, CAS

SAPINDACEAE
Acer negundo L., P scap, North American, NAT

SIMAROUBACEAE
Ailanthus altissima (Mill.) Swingle, P scap, Asian, INV

SOLANACEAE
Datura stramonium L., T scap, Wide distribution, INV
Nicotiana tabacum L., H scap, North American, CAS
Physalis angulata L., T scap, American, CAS
Solanum chenopodioides Lam., T scap, South American, NAT
Solanum lycopersicum L., T scap, South American, CAS

ULMACEAE
Ulmus laevis Pall., P scap, Middle European, CAS
Ulmus pumila L., P scap-P caesp, East Asian, CAS

URTICACEAE
Boehmeria nivea (L.) Gaudich., H caesp, Asian, CAS

VERBENACEAE
**Lantana camara* L., P caesp, Tropical, CAS

VITACEAE
Vitis ×instabilis Ardenghi, Galasso, Banfi & Lastrucci, P lian, European, NAT
Vitis riparia Michx., P lian, North American, INV

Prevalent life forms (Fig. 1) resulted to be therophytes and phanerophytes (30 taxa each, corresponding to 28.8% of the flora). Therophytes are annual species, which usually suggest xeric conditions in habitats such as pastures, uncultivated lands, or synanthropic environments (see e.g., Iamonico 2022). The high percentage of therophytes in freshwater ecosystems can be explained since the recorded taxa are able to colonize places characterized by ecological conditions not strictly related to the presence of water [e.g. *Euphorbia nutans* Lag., *Nicotiana tabacum* L., *Prunus persica* (L.) Batsch, *Solanum chenopodioides* Lam.].

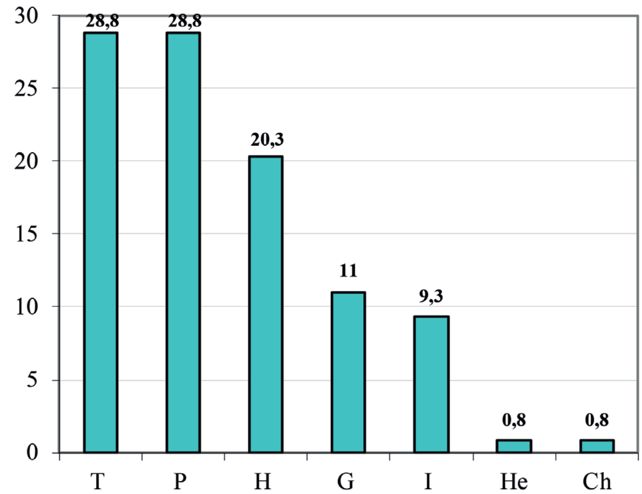

Figure 1. Percentage (axis y) of plant life form spectra of the vascular alien flora of aquatic, riparian, and humid habitats in Lazio region. T: therophytes; P: phanerophytes; H: hemicryptophytes; I: hydrophytes; G: geophytes; He: helophytes; Ch: chamaephytes.

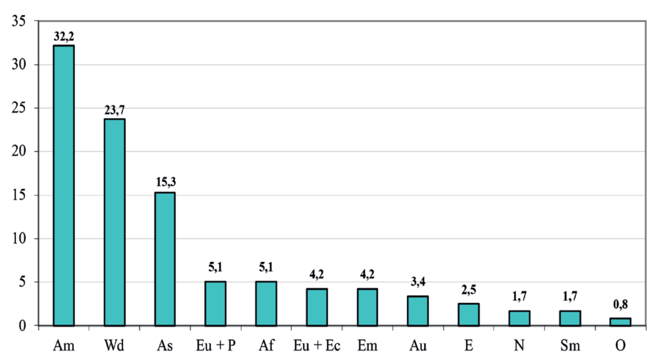

Figure 2. Chorological spectrum of the vascular alien flora of aquatic, riparian, and humid habitats in Lazio region (percentages along axis y). Am: Americas; Wd: Wide distribution; As: Asia; Eu + P: Eurasian + Paleotemperate; Af: South Africa; Eu + Ec: European + Euro-Caucasian; Em: Eurimediterranean; Au: Australia; E: Eastern; N: Nordic; Sm: Stenomediterranean; O: Orophytes-South-East-European.

The chorological spectrum (Fig. 2) shows a high percentage of wide distributed species (Cosmopolitan, Subcosmopolitan, and Tropical; 28 taxa, 23.7%), revealing the occurrence and spread of r-selected species in regional freshwater ecosystems. Most of the aliens are native to the Americas (38 taxa; 33,2%), confirming the high migration flow between the New and Old Worlds (see also Lucchese, 2017).

The distribution of taxa per habitat shows that some taxa occur in more than one habitat. Aliens that exclusively grow in riparian habitats are 19 (16.1%), while 56 taxa (corresponding to 47.5%) also occur in other places (uncultivated lands, walls, sidewalks, etc.). Humid habitats host 23 taxa (19.5%), while 11 taxa (9.3%) are exclusive to aquatic habitat. Finally, there are 8 taxa (6.8%) occurring in both aquatic and riparian habitats. Although non-native species of aquatic habitats are few, they include the higher percentage of invasive (27.3%). The number of invasive species decreases based on inundation rates of the habitat (see Tab.1), whereas the casual increase (Fig. 3).

The relationship between habitats and biological forms (Fig. 4) shows that: 1) aquatic habitats include mostly hydrophytes, 2) phanerophytes represent the most common biological form in riparian habitats, 3) the most represented biological forms in humid habitats are hemicryptophytes (39.1%) and therophytes (34.8%), and 4) chamaephytes and helophytes are overall rare.

The regional territory is intercepted by four hydroecoregions (HER11 "Toscana", HER13 "Appennino Centrale", HER14 "Roma-Viterbese", and HER15 "Basso Lazio"; Fig. 5). HER14 (the wider hydroecoregion in the region and embracing the Metropolitan City of Rome Capital) hosts 95 taxa, followed by HER15 (63 taxa), HER13 (43 taxa), and HER11 (21 taxa). The status of naturalization (Fig. 6) shows a high percentage of invasives in HER13 (33.3%), probably due to the occurrence of industrial sites in the Sacco river valley (Frosinone Province).

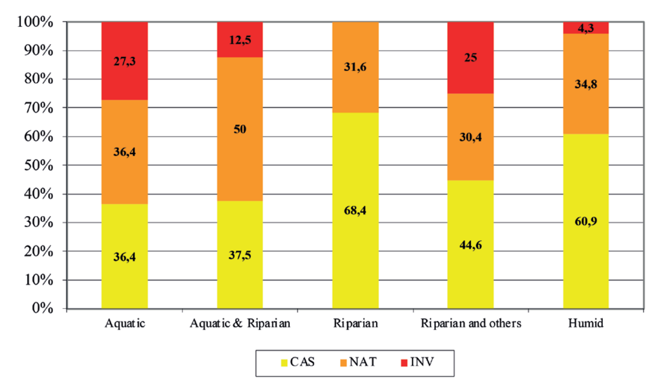

Figure 3. Percentage of casual, naturalized, and invasive taxa (axis y) per habitat (axis x).

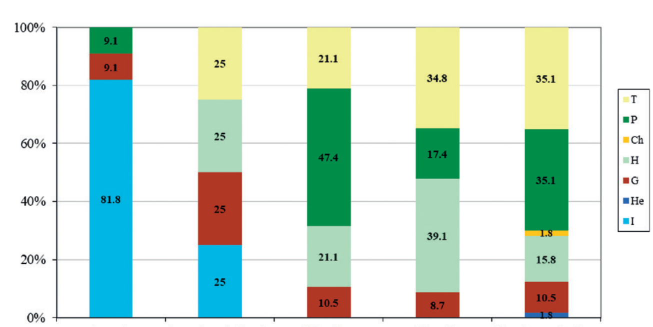

Figure 4. Percentage of biological forms (axis y) per habitat (axis x). T: therophytes; P: phanerophytes; ; Ch: chamaephytes; H: hemicryptophytes; G: geophytes; He: helophytes; I: hydrophytes.

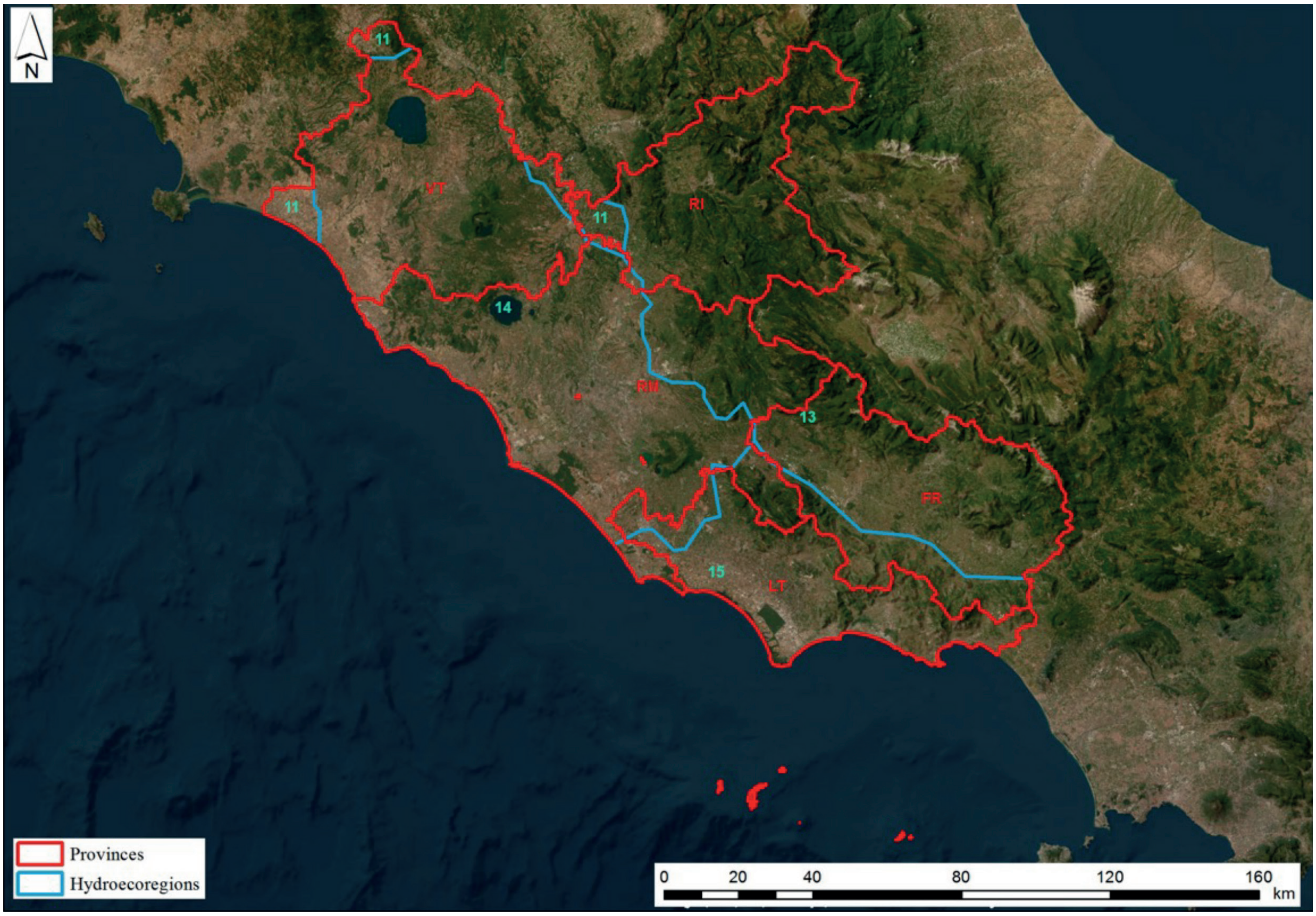

Figure 5. Hydroecoregions in Lazio region. Numbers 11, 13, 14 e 15 refer hydroecoregions codes "Toscana", "Appennino Centrale", "Roma_Viterbese", and "Basso Lazio" respectively. Codes for administrative provinces: VT = Viterbo; RI = Rieti; RM = Rome; FR = Frosinone; LT = Latina.

Concluding remarks

Freshwater ecosystems are very affected by biological invasions throughout Europe, with a high rate of recorded IAS (Invasive Alien Species) (European Environment Agency 2020; Polce et al., 2023). These ecosystems are also highly vulnerable to other different stressors (such as water eutrophication, land-use change, increasing temperatures), which may trigger irreversible shifts upon which biodiversity and ecosystem services may be lost (Angeler et al., 2014). In this context, non-native species amplify the whole vulnerability of freshwater ecosystems to environmental changes (Angeler et al., 2014) so that they necessarily must be controlled and managed, starting from floristic listing and characterization (Haber, 1997; Wu et al., 2008; Langmayer & Lapin, 2020; Balogianni et al., 2022; Wagensommer, 2023).

The assessment performed for compiling the Red List of Ecosystems of Italy confirmed such a co-occurrence of threats (Blasi et al., 2023; Capotorti et al., 2023), especially for the following ecosystem types that occur in the Tyrrhenian ecoregion (approximately coincident with HER14 plus HER15 in Lazio region):

– the peninsular riparian forest ecosystems with *Salix alba* L., *S. purpurea* L.subsp. *purpurea, S. brutia* Brullo & Spamp., *Populus alba* L., *P. nigra* L. subsp. *nigra*, *Alnus glutinosa* (L.) Gaertn., *Fraxinus angustifolia* Vahl subsp. *oxycarpa* (M.Bieb. ex Willd) Franco & Rocha Afonso, *Hypericum hircinum* L. subsp. *Majus* (Aiton) N.Robson, assessed as endangered because of a forecasted increasing trend in biological invasion combined with a declining distribution and negative effects from intensive agriculture;

– the peninsular riparian hygrophilous freshwater ecosystems with *Phragmites australis* (Cav.) Trin. ex Steud., *Typha* sp. pl., *Carex riparia* Curtis, *C. acuta* L., *Agrostis stolonifera* L. subsp. *stolonifera, Ranunculus flammula* L., *Scirpoides holoschoenus* (L.) Soják, *Paspalum* sp. pl., *Scrophularia canina* L., *Helichrysum*

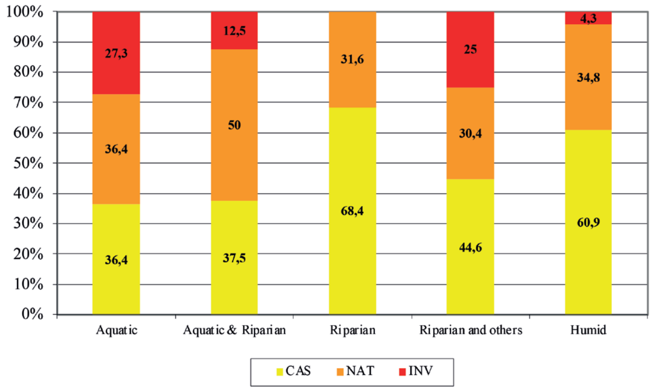

Figure 6. Percentage of casual, naturalized, and invasive taxa (axis y) per hydroecoregions (axis x). HER11: "Toscana"; HER13: "Appennino Centrale"; HER14: "Roma_Viterbese"; HER15: "Basso Lazio".

italicum (Roth) G.Don subsp. *italicum,* assessed as vulnerable because of current and forecasted trend in biological invasion combined with soil sealing and negative effects from intensive agriculture;

– the peninsular running freshwater hydrophytic ecosystems with *Ranunculus trichophyllus* Chaix*, Helosciadium nodiflorum* (L.) W.D.J.Koch subsp. *nodiflorum*, *H. inundatum* (L.) W.D.J.Koch, *Glyceria fluitans* (L.) R.Br., *Baldellia ranunculoides* (L.) Parl., *Nasturtium officinale* W.T.Aiton, assessed as vulnerable because of forecasted trend in biological invasion combined with a declining distribution, soil sealing, poor biological quality of waters and negative effects from intensive agriculture.

With an increased detail, the analyses here presented highlighted that most impacted natural freshwater ecosystems in Lazio region are related to aquatic and riparian habitats. Aquatic habitats host the highest proportion of IAS (27.3% on the total non-native species therein occurring), whereas riparian habitats host the highest absolute number of IAS (14). Aliens in aquatic habitats, particularly dangerous to biodiversity due to the ability to compete for space and natural resources (light, nutrients, etc.), include the following free-floating macrophytes that can be considered especially detrimental: *Alternanthera philoxeroides* (see e.g., Iamonico & Sánchez-Del Pino 2016), *Lemna minuta* (Ceschin et al., 2016), *Ludwigia peploides* (Gori et al., 2023), and *Pontederia crassipes* (Brundu et al., 2013) (Fig. 7). These species are characterized by vigorous vegetative reproduction and tend to form highly dense mats which not only positively compete which the autochthonous flora (especially for light; Lind et al., 2022) but also change the physico-chemical features of the water body (by reducing light penetration that, in turn, causes a variation of nutrient cycling and a reduction of ecosystem resistance to the invasion).

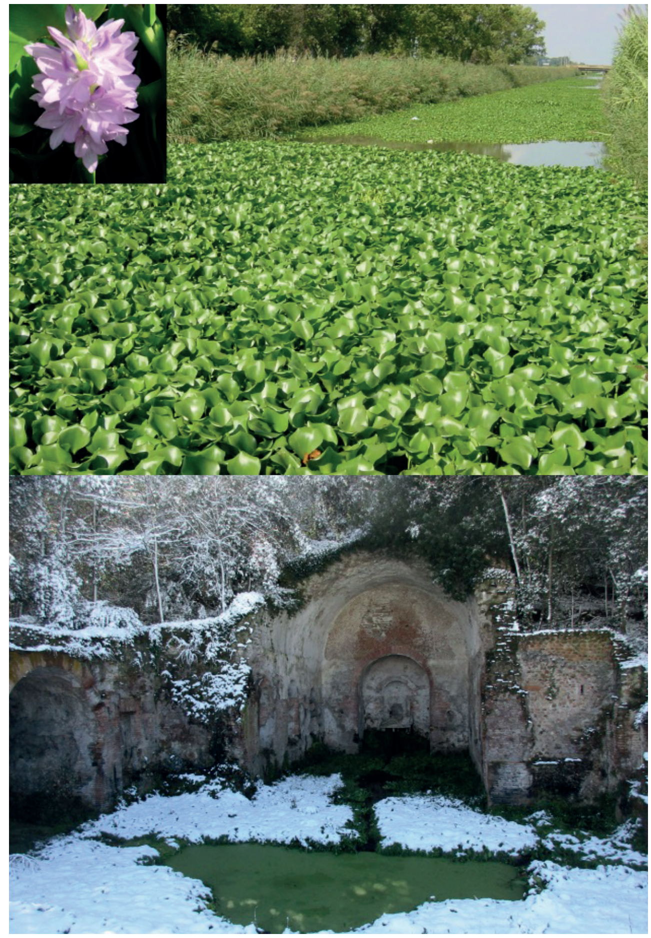

Figure 7. *Pontederia crassipes* (top image; photo by M. Iberite) at località "Canale della Botte" (Borgo Ermada, Latina city) and *Lemna minuta* (bottom image; photo by D. Iamonico) in aquatic habitat of Egeria nymphaeum during snowfall in February 2018 (Caffarella valley, Regional Park of Appia Antica, Rome).

Figure 8. *Arundo donax* along Almone river (Rome city) (photo by D. Iamonico).

Concerning the areas regularly or occasionally inundated (riparian habitats), the species that causes major threat seem to be *Arundo donax* (Fanelli, 2002) and *Robinia pseudoacacia* (Lucchese, 2017), which commonly form monospecific populations (Fig. 8). Specifically, *R. pseudoacacia* (reproducing both from seeds and by sprouting from the roots) sometimes even completely replace native riparian vegetation dominated by *Populus* sp. pl. and *Salix* sp. pl. and competes for pollinating bees (Branquart et al., 2015).
Due to the important role of riparian and humid habitats, in both ecological terms (Geist, 2011) and ecosystem services capacity (Vári et al., 2022), we argue for a continue monitoring of alien species growing in these environments with the final aim to carry out actions for control/reduction and, when possible, complete eradication of most threatening populations.

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