INVASIVE AQUATIC PLANTS AS STRESSORS OF FRESHWATER AQUATIC ECOSYSTEMS

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ABSTRACT

This paper documents the different ways in which invasive alien species are introduced into new areas. The pathways by which invasive alien species spread, their history, and the characteristics of plants that enable them to spread successfully are described. The article discusses the competitive abilities of invasive alien species, their negative effects on other organisms, and the impact of global change on their spread.

RÉSUMÉ: Les plantes aquatiques envahissantes comme facteurs de stress pour les écosystèmes d’eau douce.

Cet article documente les différentes manières d’introduire des espèces exotiques envahissantes dans les nouvelles zones. Les voies par lesquelles les espèces exotiques envahissantes se propagent, leur histoire et les caractéristiques des plantes qui leur permettent de se propager avec succès sont décrites. L’article discute des capacités compétitives des espèces exotiques envahissantes, de leurs effets négatifs sur d’autres organismes et de l’impact du changement global sur leur propagation.

REZUMAT: Plantele acvatice invazive ca stressor al ecosistemelor acvatice dulcicole.

Această lucrare documentează diferitele modalități de introducere a speciilor exotice invazive în zone noi. Sunt descrise căile prin care se răspândesc speciile alogene invazive, istoria lor și caracteristicile plantelor care le permit să se răspândească cu succes. Articolul discută abilitățile competitive ale speciilor alogene invazive, efectele lor negative asupra altor organisme și impactul schimbărilor globale asupra răspândirii lor.

INTRODUCTION

Aquatic ecosystems are vulnerable to any changes in their environments due to the effects of a wide variety of stressors, which have negative impacts (Błońska et al., 2024; Bănăduc et al., 2024, 2023, 2022).

Aquatic plants are especially vulnerable to any changes in their environment and their habitats are disappearing at a much higher rate compared to terrestrial environments. Although freshwater represent only a small proportion of all water on Earth, it plays an extraordinary and irreplaceable role for humans. Despite many ambitious European goals and measures, such as WFD 2000/60/EC, Natura 2000, and EU Green Deal, over 75% of all European freshwaters have been anthropogenically changed (IPBES, 2019).

In their work, Macedo et al. (2024) stressed that invasive plants strongly impact aquatic ecosystem composition, structure and productivity. They also assessed the economic costs of these plants. Many alien plants have strong negative effect on aquatic ecosystems by blocking rivers, disabling the survival of aquatic animals and plants by decreasing dissolved oxygen, and reducing native biodiversity (Wu and Ding, 2019). Invasive species pose severe threats to native wildlife, with about 42% of Red List species being threatened by invasive species. Invasive species also have a negative impact on human health and the economy. For example, Havel et al. (2015) reported in their comprehensive review that the dispersion of microbes over long distances and infection of new hosts have consequences for human health.

Invasive aquatic species (IAS) affect water quality and reduce recreational and educational opportunities. Many aquatic IAS reproduce very quickly, reduce the habitats of native plant species, have a negative effect on fish, insects, and other animal species, and lower the biological diversity of aquatic ecosystems (Fig. 1).

Many alien aquatic plants are deliberately introduced to new areas because they have economic, ornamental, or health values. Aquatic plants grown in aquaria need a human-mediated, intended or unintended transportation to reach the water bodies (Hill et al., 2020; Hussner, 2010). Invasive aquatic species are spread by equipment and in ballast water e.g. on ships. Species also spread without human assistance, but human activity has dramatically increased Ithe spread rate of IAS (Kolar and Lodge, 2000).

The number of alien aquatic plants in Europe has doubled since 1980 and is still increasing. Global changes are another important factor accelerating the invasiveness of specific IAS (Lind et al., 2022). The competitive success of IAS has been reported to depend on environmental conditions (Mazej Grudnik and Germ, 2013). However, research on freshwater ecosystems is scarce (Reitsema et al., 2018).

Pyšek and Richardson (2010) reported that activities that reduce problems due to IAS are risk assessment, pathway and vector management, early detection of IAS, quick responses, and different approaches to alleviation and restoration.

HISTORY OF SPREADING OF AIS IN AQUATIC ENVIRONMENTS

Human travel and trade in a wide variety of goods led to the introduction of non-native species all over the world. Although the trade and movement of people are very old, this process has increased significantly in the last century, increasing the number of non-native species. Thus, biological invasions become a consequence of globalization (Meyerson and Mooney, 2007). Invasion rates are increasing worldwide, and most are the consequence of human activities (Thomaz et al., 2015). Hundreds of non-native organisms are introduced to different parts of the world each year, but not all become invasive. However, most do not survive in the newly invaded environment. Some non-native organisms cannot adapt to the new environment, or their populations are too small to reproduce successfully.

For example, the history of species *Elodea canadensis* and *Elodea nuttallii* in Italy shows that *Elodea canadensis* arrived before 1866 and had two invasion phases, while *Elodea nuttallii* arrived in the 1970s, started invading in 2000, and continued its invasion (Buldrini et al., 2023). In Slovenia, *Elodea canadensis* has been present since the 20^{th} century, while *Elodea nuttallii* was discovered in the Drava and Ledava rivers in 2007 (Király et al., 2007). The former does not express its invasive character in natural water bodies (Kuhar et al., 2010), while the latter spreads in Slovenian rivers and outcompete *Elodea canadensis*. In Serbia, Vukov et al. (2017) and Janauer et al. (2021) reported that *Elodea canadensis* and *Elodea nuttallii* rapidly spread along the entire Danube. *Elodea canadensis* and *Elodea nuttallii* have also been recorded in Croatia; *E*. canadensis was first recorded near the city of Sisak before 1883 (Vilović et al., 2020), while the first record for *Elodea nuttallii* goes back to 2006, when it was found in the drainage canals of Kopački Rit (Kočić et al., 2014).

DO GLOBAL CHANGES PROMOTE OR INHIBIT THE PERFORMANCE OF NON-NATIVE AQUATIC PLANTS?

Climate change leads to increased environmental fluctuations, which have evolutionary consequences for all biota and increase the risk of alien species invasions into areas where they have not been before, as these species benefit from disturbances (Saarinen et al., 2019).

Climate change will cause more frequent extreme events, such as heavy rain and drought, strongly impacting hydrological conditions in riverine ecosystems, including flow velocity and evapotranspiration, which will cause drought or runoff from heavy rainfall. All these processes will lead to an increased input of autochthonous organic matter and elevated levels of dissolved organic carbon (DOC) and CO_2, resulting from degradational processes in water and sediment (Reitsema et al., 2018).

Lind et al. (2022) recently reported the possible consequences of global change in lentic ecosystems. The authors stated that the effects of climate change may lead to an increased abundance and distribution of emergent and floating species and a reduced abundance and distribution of submerged macrophytes, which are most sensitive to global changes. The same authors also claimed that an increase in invasive species would probably occur at high latitudes but not at high altitudes. This makes the lakes at higher altitudes in tropical areas hotspots for future conservation measures to protect endemic macrophyte species. The *Elodea* population, for example, was first documented in Alaska, in Eyak Lake in the Cordova area, in 1982. *Elodea* was also the first invasive aquatic plant in Alaskan waterbodies (Carey et al., 2016). Due to global climate change, boreal habitats are more vulnerable to biological invasions (Tattersdill et al., 2017). In their research, Zelnik et al. (2022) found a positive correlation between the abundance of *Elodea nuttallii* and water temperature. Similarly, in the upper reach of the Drava in Slovenia, *Elodea nuttallii* has spread large stands in warmer years with high winter and spring water temperatures (Mazej Grudnik et al., 2014). Global climate change trends show a global increase in average annual temperatures, and *Elodea nuttallii* will probably spread even more successfully in certain water bodies.

TRAITS, THAT ENABLE INVASIVE ALIEN AQUATIC PLANTS (IAAPS) SUCCESSFUL INVADING

Aquatic plants have different growth forms, from submerged to natant and emerged. Invasive alien aquatic plants **(**IAAPs) can grow in other growth forms and in unfavourable habitat conditions for a certain period (Hussner et al., 2021), which makes them competitive and successful. IAAPs can outcompete slower-growing species and form large stands within a short period because they have extensive growth (Hussner et al., 2021). Besides rapid growth and high offspring, important determinants of plant invasiveness are the production and long-distance dispersal of propagules (Goodwin et al., 1999). *Elodea canadensis* and *Elodea nuttallii* successfully reach new niches by spreading their fragments, so any disturbance in the water bodies can expand IAAPs growth.

Clonal growth enables plant growth and provides a competitive advantage in certain environments (Wang et al., 2016). Phenotypic plasticity is an important trait of successful competitors. IAAPs with a high phenotypic plasticity have a competitive advantage over (native) species with a lower plasticity (Geng et al., 2006). For example, *Elodea canadensis* and *Elodea nuttallii* have high growth rates and are highly tolerant of various environmental conditions: they are shown to have low vulnerability to grazing and other stress factors, with high distribution and reproduction potential. Both are also highly resistant to common conventional aquatic weed management measures (Zehnsdorf et al., 2015). For example, in the oxbow of the Sava river in Slovenia, *Pistia stratiotes* outcompeted autochthonous aquatic vegetation and altered the ecological balance (Jaklič et al., 2020). In addition, in Wadi Al Jawahir in Fez, Morocco, *Pistia stratiotes* expanded in the last decade, even though preventive measures were implemented (Chadli et al., 2023). The authors also demonstated in their laboratory study that biomass reduction of *Pistia stratiotes* due to liming, drainage, and surface aeration are successful control methods for its development.

TEMPERATE WATER BODIES AS FOOD STEPS FOR IAS

In central Europe, *Pistia stratiotes*, an invasive alien species, was introduced near Prilipe, an oxbow in Slovenia, in 2001 in a temperate climate zone. Šajna et al. (2007) reported on the successful winter survival of *Pistia stratiotes* in a natural thermal stream. In addition to the vegetative propagation of *Pistia stratiotes,* which is well documented, a well-established and viable seed bank has also been detected in the lake sediment and along the banks of the lake after winter floods. The athors warn that special attention must be given to the thermal water ecosystems in temperate climates in the future. Warm water bodies can serve as stepping stones and centers for the spread of invasive species from (sub-)tropical areas. Climate change and global warming can accelerate the establishment of such local populations of invasive species, making them stepping stones for further dispersal (Jaklič et al., 2020). Šajna et al. (2023) recently stated that although most thermophile alien plants result from deliberate introductions, thermally abnormal waters pose an invasion risk for further deliberate introductions, particularly for free-floating macrophytes.

THE EFFECT OF INVASIVE *ELODEA* ON SPECIES DIVERSITY IN SLOVENIA

In the research by Kuhar et al. (2010), 39 watercourses were surveyed in Slovenia, and *Elodea canadensis* was rarely found as the prevailing species and never as the only species in any of them. The authors concluded that *Elodea canadensis* did not express its invasive character due to the heterogeneous watercourses with a high diversity of macrophytes.

Zelnik et al. (2022) recently studied whether the diversity of macrophytes in natural and man-made waterbodies located on the floodplain along the Drava River in Slovenia is affected by the presence of alien invasive species *Elodea canadensis* and *Elodea nuttallii*. They discovered that *Elodea canadensis* and *Elodea nuttallii* were present in 19 out of 32 sample sites and that *Elodea nuttallii* prevailed. The less invasive *Elodea canadensis* did not grow in ponds and oxbow lakes but was relatively abundant in side-channels. On the other hand, *Elodea nuttallii* was present in all types of such habitats and was dominant in ponds. For example, it was recently reported in Croatia that *Elodea canadensis* was found mostly in rivers, while *Elodea nuttallii* was mostly found in artificial canals (Bučar et al., 2024). Zelnik et al. (2022) found no negative effect of the alien invasive *Elodea* species on the species richness and diversity of native flora.

The study by Mazej Grudnik and Germ (2013) showed that the distribution of alien species *Elodea nuttallii* was suppressed in river stretches exposed to high turbulence. On the other hand, autochthonous species M*yriophyllum spicatum* was more abundant than *Elodea nuttallii* in stretches exposed to higher flow velocity. This study demonstrated that the competitive success of M*yriophyllum spicatum* and *Elodea nuttallii* depended on environmental conditions.

BENEFITS FROM IAS

The introduction of alien species is mainly thought to be detrimental to invaded ecosystems, although there are also some positive effects (Fig. 1). For example, the study by Alford and Rozas (2019) provides an example of the positive effects of alien Eurasian Watermilfoil, *Myriophyllum spicatum*. The authors identified no adverse effects of *Myriophyllum spicatum* on juvenile white shrimp or other species of nekton compared to native submerged aquatic vegetation. Moreover, the nursery value of *Myriophyllum spicatum* for juvenile white shrimp was relatively high compared to *Ruppia maritima*, the native submerged aquatic species (Alford and Rozas, 2019). In their recent review, Kourantidou et al. (2022) also stated that IAS can have potentially beneficial roles.

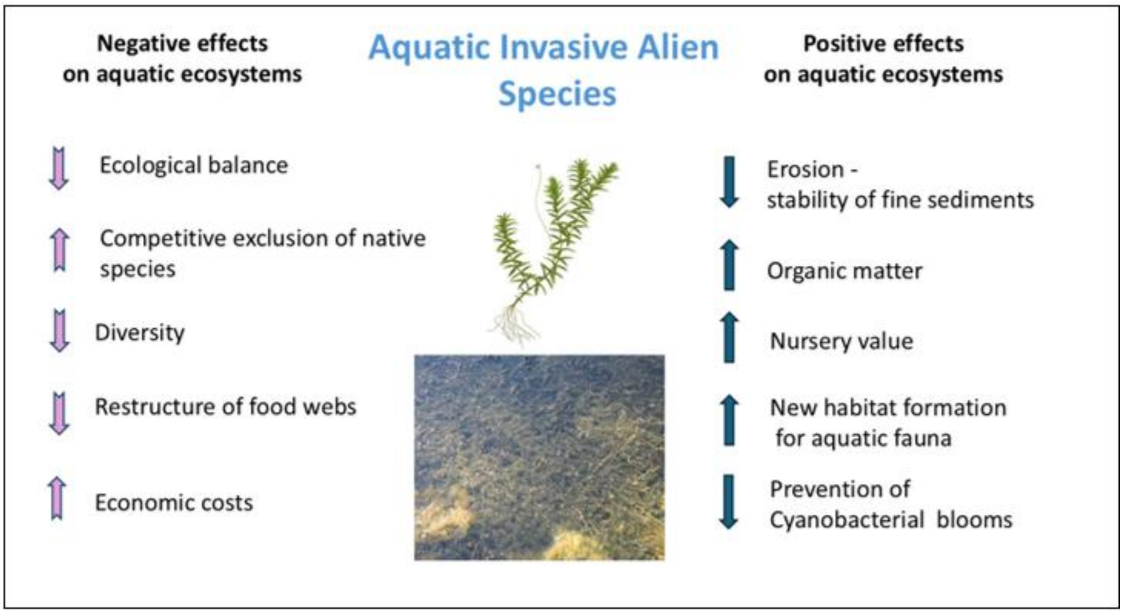

Figure 1: Negative and positive effects of aquatic invasive alien species.

CONCLUSIONS

Managing and removing invasive species is a major problem in the field of invasion biology (Kovalenko et al., 2021). We cannot prevent the spread of IAS to new areas in the world. With increasing globalization and climate change, their occurrence will only increase. Therefore, it is crucial not to intentionally introduce alien organisms into nature and, on the other hand, to try to benefit from IAS.

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