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MÁRIO SÉRGIO DAINEZ FILHO

From local monitoring to a global inventory of aquatic macrophyte introductions – insights for monitoring and preventing species invasions

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Tese apresentada ao Programa de Pós-Graduação em Ecologia de Ambientes Aquáticos Continentais do Departamento de Biologia, Centro de Ciências Biológicas da Universidade Estadual de Maringá, como requisito parcial para obtenção do título de Doutor em Ecologia e Limnologia.
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‘A ignorância se alimenta de ignorância.

A fobia da ciência é contagiosa.’

Carl Sagan

De monitoramentos locais até um inventário global das introduções de macrófitas aquáticas – *insights* para monitoramento e prevenção de invasões de espécies

RESUMO

Os ecossistemas aquáticos são especialmente vulneráveis à invasão de espécies devido a sua grande extensão, diversidade de *habitat* e a dinâmica inerente destes *habitat*. Macrófitas aquáticas invasoras geram muita preocupação devido à sua grande influência nos ecossistemas aquáticos. Buscou-se contribuir para o campo das invasões biológicas de macrófitas aquáticas em nível regional e global com conhecimentos pertinentes ao monitoramento e prevenção de espécies introduzidas. Na primeira abordagem avaliou-se a invasão de uma das espécies de macrófitas invasoras mais preocupantes do mundo, *Hydrilla verticillata* (L.f.) Royle, em diferentes tipos de ambientes de uma planície subtropical. Investigou-se a relação das ocorrências desta espécie com seus principais preditores abióticos, bem como sua relação com a espécie nativa (morfologicamente semelhante) *Egeria najas* Planch. nos primeiros anos de sua introdução e 10 anos depois. Tal trabalho destacou as interações bióticas entre a espécie invasora e a nativa bem como mudanças nos preditores ambientais que sugerem impactos antrópicos merecedores de atenção. Uma segunda abordagem foi realizada com o intuito de alavancar o conhecimento sobre macrófitas aquáticas invasoras em um nível global. Foi realizada uma compilação de dados acerca das vias e caminhos de introdução das macrófitas aquáticas a fim de identificar as regiões de origem e destino destas espécies e de seus respectivos grupos funcionais. Tais informações são cruciais para a determinação de políticas públicas e estratégias de manejo para evitar a introdução de espécies indesejadas. Em suma, os resultados das duas abordagens dão suporte a caracterização das invasões de macrófitas aquáticas visando sua prevenção.

Palavras-chave: Invasões biológicas. Monitoramento. Ambientes aquáticos. Vias de introdução. Distribuição de espécies.

From local monitoring to a global inventory of invasive aquatic macrophyte introductions - insights for monitoring and preventing species invasions

ABSTRACT

Aquatic ecosystems are especially vulnerable to species invasion due to their extent, diversity of habitats, and inherent dynamics. Invasive aquatic macrophytes are of great concern because of their great influence on aquatic ecosystems. In this thesis, we sought to contribute to the field of biological invasions of aquatic macrophytes at regional and global levels using knowledge pertinent to monitoring and preventing the introduction of species. Given that, one of the most concerning invasive species in the world, *Hydrilla verticillata* (L.f.) Royle, was evaluated in different types of environments in a subtropical floodplain. The relationship of occurrences of this species with its main abiotic predictors was investigated, as well as its relationship with the native (equivalent) species *Egeria najas* Planch. right after its detection and 10 years later. This work contributed with insights regarding the biotic interactions of invaders and natives as well as changes in environmental predictors that highlight anthropogenic impacts that deserve attention. A second work was carried out to leverage knowledge about invasive aquatic macrophytes at a global level. A compilation of data from several available sources was carried regarding the most common pathways of introduction of aquatic macrophytes to identify the regions of origin and destination of these species and their respective functional groups. Such information is crucial for the determination of public policies and management strategies to avoid the introduction of unwanted species. In summary, this thesis helps the characterization of aquatic macrophyte invasions aiming at their prevention.

Keywords: Biological invasions. Monitoring. Aquatic environments. Pathways of introduction. Species distribution.

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SUMMARY

1 GENERAL INTRODUCTION

Humans have been introducing species beyond their native areas for centuries (Simberloff et al., 2013). Some of these species proliferate in such a way that they threaten biodiversity and ecosystem functioning (Gallardo et al., 2016), generating ecological, economic and even social impacts (Pimentel et al., 2005, Simberloff & Rejmanek, 2011).

Freshwater ecosystems are especially vulnerable to the introduction of species due to their large extension, diversity of habitats and the nature of processes related to these environments that increase the connectivity and dispersion of organisms between habitats, such as the flood pulse (García-Berthou & Moyle, 2011 ; Zedler, 2011). In addition, freshwater aquatic environments concentrate the greatest biodiversity per unit area of the planet, despite occupying a small fraction of the earth's surface (Dudgeon et al., 2006), which highlights the relevance of knowledge about biological invasions in these areas. environments.

Among the invasive species in aquatic ecosystems, aquatic macrophytes are noteworthy. Aquatic vegetation plays a crucial role in freshwater ecosystems. They provide biomass (primary production), shelter and food for many species, affect the chemical composition of water and sediments, increase heterogeneity and spatial complexity, and influence the change between alternative stable states (dark or clear water) (eg Engelhardt and Ritchie , 2001; Henninger et al, 2009; Cunha et al, 2012; Bakker et al, 2016; Moi et al, 2020). Consequently, the uncontrolled growth of these plants, when they become invasive, can lead to systemic damage to aquatic ecosystems (Gallardo et al., 2016; Rai and Singh, 2020). In this way, invasive aquatic macrophytes have been investigated in a myriad of different scopes in the field of Invasion Ecology to understand the causes, consequences, and necessary actions against such introductions.

Due to problems related to species invasion, actions taken by managers must follow a hierarchy in terms of management efficiency and cost (Simberloff et al., 2013). "Prevention" has priority (and lowest cost) followed by "Early detection" (interception, monitoring, removal) and, in the latter case containing the highest cost and worst efficiency, "Management" (eradication, containment and control) (Simberloff et al., 2013; Robertson et al., 2020).

Unfortunately, there are many cases of successful invasions of various aquatic ecosystems around the world (Simberloff & Rejmanek, 2011). For cases that do not yet pose a threat, the best remaining strategy is monitoring and surveillance to avoid future impacts (Simberloff et al., 2013). Thus, in the first approach of this thesis, entitled "Ten years of *Hydrilla verticillata* (Lf) Royle invasion in a tropical floodplain – Spatial and temporal patterns", one of the most worrying invasive macrophyte species in the world was evaluated (Langeland, 1996) 10 years after its introduction into the upper Paraná River floodplain. This article contributes to "Early Detection" strategies, specifically within the scope of monitoring and surveillance (Simberloff et al., 2013). Such knowledge is invaluable for decision-makers in the studied area and in other RAMSAR sites to choose better monitoring and management strategies.

In order to provide managers with the possibility of anticipating the introduction of aquatic macrophytes, another study was carried out to support the prevention of such introductions. In the second approach of this thesis, entitled "Macrophyte invasions – A global overview of occurrence and pathways of introduction", a global dataset was built to identify the most common routes of introduction of naturalized macrophytes, which are introduced species that maintain populations self-sustainable in the invaded environment. Concomitantly, it was identified which are the regions of origin and destination of these species of macrophytes and their functional groups. Such knowledge is invaluable for decision makers in the studied area and in other wetland sites of international importance (RAMSAR sites) to choose better monitoring and management strategies.

The combination of investigation of an invasive species and the characteristics of the receiving ecosystem (first approach), as well as knowledge about the introduction routes and functional traits of such organisms (second approach) are essential to characterize the so-called Invasion Syndromes (Novoa et al., 2020) thus increasing the ability to predict and manage biological invasions. Thus, the aim was to provide knowledge that will effectively contribute to defining aquatic macrophyte invasion syndromes.

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2 TEN YEARS OF *HYDRILLA VERTICILLATA* (L.F.) ROYLE INVASION IN A TROPICAL FLOODPLAIN: SPATIAL AND TEMPORAL PATTERNS

ABSTRACT

Invasive species demand constant surveillance to evaluate their impacts or the effects of management strategies. Here we investigated the invasion of *Hydrilla verticillata* (L.f.) Royle in a subtropical floodplain, assessing the relationship between the occurrences of this species and its main abiotic predictors, as well as its relationship with the native (equivalent) species *Egeria najas* Planch. For that, we used data from monitoring samples that represent two periods of *H. verticillata* invasion: T1 - right after its first detection (2007-2008) and T2 – ca. 10 years later (2015-2017). *Hydrilla verticillata* still seems to be limited to the area of the floodplain in which it was at the beginning of its invasion (mainly in lotic sites). However, we found more occurrences of *H. verticillata* in lentic habitats in T2 than in T1. Such finding seems to be related to the increase in water transparency (the main predictor of *H. verticillata* occurrences) in these sites over time due to the impacts of dams, however it does not seem to be concerning yet once we found no evidence that *H. verticillata* is replacing the native *E. najas*. We found evidence of facilitation between both species that deserves to be investigated deeply. Our findings suggest that there is no need for management actions to control *H. verticillata* in the study area for now. However, we strongly recommend the constant surveillance of *H. verticillata* along with the impacts of upstream reservoirs on the abiotic characteristics of floodplains.

Key words: Biological invasions; Hydrocharitaceae; Invasiviness; *Egeria najas*; Upper Paraná River floodplain.

2.1 Introduction

Evaluating ecological processes depends on many idiosyncrasies (Sutherland et al., 2013; Simberloff, 2004). In the case of biological invasions, factors related to the invasibility i.e., the properties that determine the inherent vulnerability of a habitat, community or ecosystem to invasion (Richardson et al., 2011) and invasiveness i.e., the features of an alien organism that define their capacity to invade (Richardson et al., 2011) emerge. For example, there may be fluctuations in the resource availability that open windows for the establishment of invaders (Davis et al., 2000) and/or higher invaders performance in the new environment that increases the invader competitiveness compared to the resident species (Blossey & Nötzold, 1995; Callaway & Ridenour, 2004). Thus, depending on the environment-invader relationship, species introductions can result in impacts on the recipient environment (Simberloff et al., 2011).

Considering that the stages of invasions (introduction, colonization and naturalization) are context dependent, the time between the introduction of a new species and its impacts is sometimes uncertain (Crooks et al., 2005; Crooks, 2011). There are many examples in the literature related to lag-times between alien species arrival and their impacts on native community (Crooks, 2011). For example, there were reported ca. 40 years for quagga mussels to expand their occurrence through the Volgo-Don waterway (Orlova et al., 2005), 100 years for water hyacinth (*Eichhornia crassipes* (Mart.) Solms) started to become invasive in Italy (Brundu et al., 2013), and, in other cases, up to 200 years (see Crooks, 2011, p. 407 for more examples).

The evaluation of the impact of a introduced species depends not only on the temporal scale but also on the adopted spatial scale (Fridley et al., 2007). Studies that consider small spatial grains, including experiments and local field surveys, tend to find negative correlations between native and naturalized exotic species richness, while broad-grained studies suggest positive correlations (Fridley et al., 2007, Pulzatto et al., 2019; Tomasetto et al., 2019). However, there are exceptions, such as Lolis et al. (2020), who found negative correlations between the native macrophyte diversity and the *Eichhornia crassipes* (Mart.) Solms abundance, comparing a native and an invaded ecosystem and using a broad spatial scale.

Because of the difficulties in predicting the results of biological invasions and considering the potential damage of invasive species in all sectors of society (Simberloff et al., 2011; Pimentel et al., 2005; Simberloff et al., 2013), a preventive approach must be taken (Simberloff et al., 2013). Management strategies against invasive species follow a hierarchy in efficiency and cost (Simberloff et al., 2013). On a priority scale, "prevention" is the first strategy to be taken (lowest cost and more effective), followed by "early detection" (interception, monitoring, surveillance, and removal) and, in the last case, the long term "management" with the highest cost (eradication, containment, control) (Simberloff et al., 2013). Unfortunately, there are many cases of successful invasions that have already taken place in many different regions of the Earth (Simberloff et al., 2011), and for those that do not pose a threat yet, the best remaining strategy is monitoring and surveillance to be ahead of future impacts (Simberloff et al., 2013). In this study, we present a monitoring study of a common submerged invasive macrophyte, *Hydrilla verticillata* (L.f.) Royle over ca. 10 years since the beginning of its introduction in a South American floodplain, a key area for biodiversity conservation.

Wetlands, such as floodplains, play an important role in providing food, water supply, hydropower, carbon sequestration, flood mitigation, and a range of other services that are globally important for life maintenance and, thus, for sustainable development (RAMSAR, 2018). However, wetlands have been exploited and impacted by anthropogenic activities and are currently among the most impacted environments on Earth (Dudgeon et al., 2006; RAMSAR, 2018). In South America, one of the most strategic ecosystems for biodiversity conservation is the upper Paraná river floodplain (UPRF) – see the Study Area section. Within the Brazilian territory, this area contains more than 130 large reservoirs that flooded most of the river-floodplain system (Agostinho et al 2004). However, there is a remaining stretch (ca. 230 km long) without dams, which comprehend a mosaic of habitats hosting thousand of species of different taxa (Agostinho et al., 2004). Although this stretch is considered dam-free, it is not totally free from the influence of reservoirs (Roberto et al., 2009). Upstream reservoirs retain suspended particles and nutrients that, over time, have increased water transparency and decreased nutrient concentration in the Paraná river (i.e., oligotrophization), the main river in this river-floodplain system (Roberto et al., 2009). Furthermore, the artificial regulation of the water level caused by dams change the aspects of the flood and dry regimes (Roberto et al., 2009), which are the major triggers to the ecological processes in this type of ecosystems (Agostinho et al., 2004).

The water oligotrophization and the increase in underwater radiation have been facilitating the establishment of *H. verticillata* in the UPRF (Sousa, 2011). *Hydrilla verticillata* (Hydrocharitaceae) is a rooted submerged macrophyte, native from Asia which has spread throughout all continents except the Antarctic (Cook and Lüönd, 1982; Zhu et al., 2015). This species has a high growth ratio (Bianchini-Jr et al., 2010) and it is known as a very successful naturalized species outside its native range, where it can produce high biomass and interfere with navigation, diving activities, and clog tubulations (Langeland, 1996). The first record of this invasive macrophyte in South America (in the UPRF) was in 2005 at a reservoir located upstream of the stretch free of dams (Sousa, 2011). After a few years, this macrophyte colonized the UPRF and spread ca. of 300 km downstream through the Paraná river achieving the Itaipu reservoir (Thomaz et al., 2009; Sousa, 2011).

In 2007-2008, Sousa et al. (2009) sampled many sites across the UPRF to understand which habitats are more susceptible to *H. verticillata* colonization and which abiotic factors are the best predictors of its occurrence. The authors found that *H. verticillata* seems to be confined to the Paraná river channel while the equivalent native species *Egeria najas* Planch. (Hydrocharitaceae) (same life-form and occupy similar habitats) can also colonize floodplain lakes and other rivers (Sousa et al., 2009; 2010). However, with the influence of anthropogenic disturbances such as reservoirs, the UPRF has been modified over the years (Roberto et al., 2009), and, consequently, the resident species and the invasive species may respond to those changes. Upstream reservoirs retain suspended particles working as a sediment trap. Over time, the nutrient concentration decreased in the Paraná river channel along with the increase of the water transparency (Roberto et al., 2009) which is the main predictor of *H. verticillata* in this area (Sousa et al., 2009). The UPRF lakes, which *H. verticillata* has not been able to colonize so far, support a high richness of macrophytes (Souza et al., 2017), and thus, these abiotic changes are a cause of concern.

Our aim here is to answer two main questions: i) has *H. verticillata* expanded its occurrence area over time in the Upper Paraná River floodplain?, and ii) is *H. verticillata* affecting the probability of occurrence of the native *E. najas*? Tackling these questions should give an idea of how (and whether) the invasive macrophyte is expanding its occurrences and threatening the native species. To answer these questions, we compared the data collected by Sousa et al. (2009) in 2007-2008, right after the first record of *H. verticillata* at the UPRF with the other two samples in 2015-2017, in the same study area using the same sampling protocol.

2.2 Study area

The upper Paraná river-floodplain system (UPRF) comprises three rivers: Baía, Ivinheima, and Paraná, the main river (Fig. 1). Each river has a bunch of associated waterbodies with intrinsic characteristics, which let us split this floodplain system into three subsystems: Baía Subsystem (BS), Ivinheima Subsystem (IS), and Paraná Subsystem (PS) (Fig. 1). As a matter of facility to the reader, we used the same notation as Sousa et al. (2009) to make the papers easier to compare.

The area we focused on represents ca. 230 km between the two reservoirs (Porto Primavera and Itaipu) of the Paraná river (Fig. 1). The main driver of ecological processes in this area is the flood pulse during the summer season, November to March (Sousa-Filho et al., 2004). Higher intense flood events increase the connectivity and the similarity among the three subsystems including their associated waterbodies (Thomaz et al., 2007), facilitating the spread of invasive species, such as *H. verticillata,* across the landscape. However, flood increases the suspended particles in the rivers, especially in the Paraná river, consequently decreasing the water transparency.

Comparing the three subsystems, the Paraná River is the major river and receives water from the other two rivers (i.e., Ivinheima and Baía; Fig. 1). It is a lotic ecosystem with the highest transparency and the lowest nutrient concentration, factors that have been associated with the prevalence of *H. verticillata* in the main channel of this river (Sousa et al., 2009; 2010). The Baía river is considered semilotic and it has the highest concentration of humic compounds. This river is strongly influenced by the Paraná river flood regime. The last river, Ivinheima, is considered lotic and has the lowest water transparency. The hydrology of the last river is more independent from the Paraná river.

Sample sites were distributed across the subsystems according to Table 1. The sample sites consisted of main river channels, river channels, lakes, and backwaters. Each waterbody was classified as lotic or lentic (Table 1).

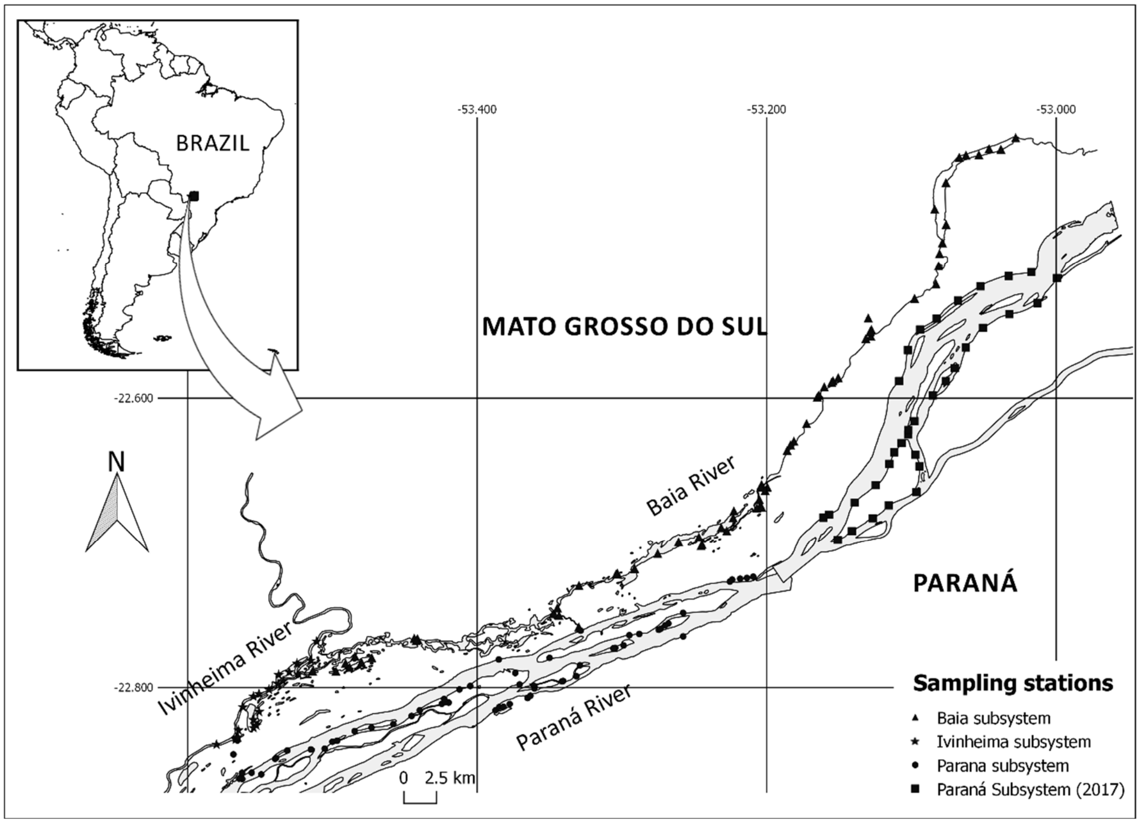

Fig. 1 – Map of the sampling stations in the UPRF (adapted from Sousa et al., 2009). Squares refer to additional sites sampled in 2017 at Paraná subsystem.

2.3 Methods

To evaluate *H. verticillata* invasion in space and time, we used data from two periods, right after *H. verticillata* first record in the UPRF and ca. ten years later. For the first period (T1) we used data from Sousa et al. (2009), referent to November 2007 and April 2008. For the second period (T2), we combine data collected in February 2015 and

November 2017. We did not use the full data set of Sousa et al. (2009), which also includes one extra sampling in April 2007 (right after a major flood) to facilitate comparisons and to ensure we had coherence when comparing samples with equivalent hydrological periods. Given that, we considered two hydrological stages inside each period. Samples performed in November 2007 and April 2008 refer to low influence (LI) and high influence (HI) of the highwater period, respectively. The samples performed in February 2015 and November 2017 refer to high influence (HI) and low influence (LI) of the flood pulse, respectively (Appendix A - Figure A1).

2.3.1 Macrophyte occurrence sampling

We followed the methods of Sousa et al. (2009) in all the samples, which consisted of sampling 148 sites in the landscape in the three subsystems (Table 1). In each sample site of 2007 and 2008, macrophyte presence was checked in deeps up to 4 meters with a rake. A researcher positioned at a boat dragged the river sediment and reported the absence or the presence of macrophytes. All the sample sites had their coordinates recorded with a GPS device (Datum WGS-84) and all subsequent samples were repeated strictly at the same sites (as close as possible to the original GPS coordinate).

We utilized an anchor attached to a rope instead of the rake to resample the sites in 2015 and 2017. The latter method extends the area sampled in the sites (ca. 5 m of radius), and thus, minimizes false absences. We positioned the boat at the site during the resample, following the GPS coordinates, and we tossed the anchor up to ten times in all directions (N, S, E, and W from the sample point).

To reduce the collector's bias, we ensured that one researcher member of the Sousa et al. (2009)'s crew participated in the samples of 2015 and two members of the 2015 researchers' crew resampled the sites in 2017.

2.3.2 Abiotic variables

Following Sousa et al. (2009) guidelines, we sampled electrical conductivity (S/m) and the maximum depth of visibility of the Secchi disk (ZDS (m)) in all sites. These variables are considered the most important predictors of rooted submerged macrophyte occurrence in the study area (Sousa et al., 2009).

As water flow is an important driver for submerged macrophyte occurrence (Chambers et al., 1991), we categorized the sampled sites into two categories, "Lotic" or "Lentic", according to the features of each habitat (Table 1).

Table 1 - The number of sample sites (n) for each year of both sampling periods (First Period (T1); Second Period (T2)) referent to the number of types of waterbodies assessed, and the classification according to the water flow (Flow) for each subsystem (Subsystem).

Subsystem	Flow	First period (T1)		Second period (T2)	
		2007	2008	2015	2017
Baia	Lentic	43	33	30	35
	Lotic	21	21	18	21
Ivinheima	Lentic	15	15	3	15
	Lotic	7	7	7	7
Parana	Lentic	15	15	12	11
	Lotic	47	47	43	127
Total n		148	138	113	216

2.3.3 Sampling limitation and additions

In the sample performed in 2008 by Sousa et al. (2009) and in our resamples in 2015 and 2017, the accesses to many sampled sites were compromised due to the low water level and the high macrophyte biomass clogging the entrance of those water bodies. Neither occurrence data nor abiotic features were collected in those environments (Table 1). When access to those sample sites was available by walking, we perform the sampling procedure as close as possible to the original GPS coordinate. However, we suspended the sediment while walking because these sites were way too shallow. Therefore, we were not able to record ZDS neither conductivity. Seven sites originally sampled in Paraná river on previous samples were not sampled in 2017 because of GPS equipment issues.

Sousa et al. (2009) found a high prevalence of double absences (c.a. 70%) in the sampling on T1 (2007-2008). Double absences could be the result of spread patterns (e.g., movements of macrophytes patches) or the result of sampling variation (Legendre & Legendre, 2003). Thus, double absences are not ecological meaningful (Legendre & Legendre, 2003). To avoid this problem we sampled 87 extra sites in 2017 at the Paraná subsystem (the subsystem that the studied macrophytes are prevalent) with the presence of at least one species. This allowed decrease the prevalence of double absences in T2 (c.a. 50%) which provided a better evaluation of cooccurrence patterns of both macrophytes and the role of abiotic predictors over it.

2.3.4 Data analyses

We used logistic regression models to interpret better the variables associated with the occurrences of *H. verticillata* and *E. najas*. We decided to model the occurrence of both plants specifying which plant is occurring in the sampling site with a categorical variable "Plant" (Table 2). We also specified whether a cooccurring plant is present in a categorical variable "Cooccurrence" (Table 2). Then, we were able to investigate the effect of biological interactions between both plants. All predictors were tested for multicollinearity.

We performed a backward model selection (Zuur et al., 2009), starting from a saturated model containing all predictors in Table 2, and removing the non-significant terms in each step. We used the likelihood-ratio test ($\alpha = 0.95$) as a criterion for predictors removal (Table 3). All statistical procedures and data manipulation were performed with R (R Core Team, 2020).

Table 2- Variables used in the logistic model

Type	Variable	Description
Response	Occurrence	Presence (1) or absence (0) of submerged species
Predictors	Period	T1 (2007-2008) or T2 (2015-2017)
	Flow	Lotic or Lentic
	Plant	*Hydrilla verticillata* or *Egeria najas*
	Cooccurrence	The presence (1) or absence (0) of the cooccurring plant
	Hydrology	High influence (HI) or low influence (LI) of the flood season
	Conductivity	Electrical Conductivity (μScm^{-1})
	ZDS	Depth of disappearance of the Secchi disc (ZDS m)

We considered interactions between Flow*Cooccurrence*Period*Plant, Hydrology*Plant, Plant*Conductivity and Plant*ZDS. The final model and the selected predictors are shown in Table 3.

Table 3- Predictors selected used in the final logistic model fitted. AIC - Akaike Information Criterion; LRT - Likelihood-ratio test statistic and its assossiated p-value.

Final model:	Occurrence ~ Cooccurrence + Conductivity + Flow*Period + Flow*Plant + Plant*Secchi			
	Predictors	**AIC**	**LRT**	**p value**
	None	578.93		
	Cooccurrence	603.31	6.35	0.011
LRT Final	Conductivity	651.12	54.17	<0.001
	Flow*Period	602.37	5.41	<0.001
	Flow*Plant	618.49	21.53	<0.001
	Plant*Secchi	618.81	21.85	<0.001

2.3.5 Changes in lentic environments of Paraná Subsystem (PS)

Water transparency (ZDS) seems to be the major predictor for *H. verticillata* occurrences (Sousa et al., 2009). As the probability of *H. verticillata* occurrence increased in lentic sites of PS in T2, we compare ZDS in the lentic environments of this subsystem between T1 and T2. This would allow us to infer about the invasibility of such habitats to *H. verticillata*. Given that, we performed a two-way Anova for water transparency (Appendix B). We compare ZDS between periods (T1 and T2) and the hydrological periods (HI and LI) (Appendix B).

2.3.6 Exploring the cooccurrence of plants

To better understand the relationship between the native and the invasive macrophyte, we used the *Corrected Proportion of occurrences score* (CPO_{it}; Thomaz and Michelan, 2011).

The CPO_{it} estimates an average for pair associations that considers the frequency of occurrence of each species. This index expresses the difference between the proportion of observed and expected co-occurrences. The CPO_{it} is:

$$CPO_{it} = \frac{n_{it}}{n_i \times \frac{n_t}{N}}$$

where n_{it} is the number of sites where species *i* [*E. najas*] co-occurred with the *H. verticillata*; n_i is the total number of sites where species *i* occurred; n_t is the number of sites where species *t* [*H. verticillata*] occurred; and *N* is the total number of sites. The CPO_{it} indicates whether submerged macrophytes co-occurred more ($CPO_{it} > 1$) or less ($CPO_{it} < 1$) than expected by chance ($CPO_{it} = 1$) . To evaluate CPO_{it} we used a null model with 999 randomizations. We compared how many times the observed CPO_{it} was equal or higher than the random generated indexes.

2.4 Results

2.4.1 General results

For both periods, PS contained more than 95% of all plant occurrences, and *H. verticillata* was the most frequent macrophyte (Table 4). We found no submerged plants at IS sites during any period sampled. For BS, only a few occurrences were recorded for *E. najas*. *Hydrilla verticillata* was found growing in one sampling station at the BS during T2, however, this station was connected and very close to the Paraná river (ca. 300 m). See Appendix C to check abiotic features for each subsystem

Table 4 - Percentage of occurrences for *Hydrilla verticillata* and *Egeria najas* in each subsystem during both sampled periods. Note the percentages refer to each species separately. Then the sum of all percentages might overcome 100% because plants can coocur on sites.

Period	Subsystem	*H. verticillata (%)*	*E. najas (%)*	Coocurrences (%)
T1 (2007-2008)	BS (Baía)	0	1.70	0
	IS (Ivinheima)	0	0	0
	PS (Paraná)	48.39	24.19	11.3
T2 (2015-2017)	BS (Baía)	0.96	3.81	0
	IS (Ivinheima)	0	0	0
	PS (Paraná)	69.43	40.93	29.9

Most sites colonized by the invasive *H. verticillata* in both periods are lotic (c.a. 95%). However, the number of lentic sites (lakes and backwaters) in PS which the invasive macrophyte was found established increased in T2 (30% of the lentic sites of PS) compared to T1 (6%). The occurrences of *E. najas* also showed a prevalence in lotic sites (ca. 77%), but less prominent than *H. verticillata*. Considering all sampled sites, *Egeria najas* was found established in 12 lentic sites in T1 (83% of them in PS) and in two more lentic sites in T2 (n = 14; 78% of them in PS).

2.4.2 Logistic model

Considering the estimates from the fitted model (Table 5), there was no difference between the lotic and lentic environments in the first period (T1) for *E. najas* occurrences (OR = 0.99; p-value = 0.976). However, *E. najas* was less likely to occur in lotic environments in the second period (T2) compared to the lentic environment (OR = 0.28, p-value = 0.022). Regarding the invasive *H. verticillata*, the lotic environment was much more important (OR = 16.56, p-value < 0.001), especially in the first period, when the lentic environments were not very important for the invasive macrophyte (Table 5).

Table 5. Estimative of the parameters for the final fitted model.

Predictor	Estimate	OR	p-value
(Intercept)	-6.39	-	**<0.001**
FlowLotic	-0.01	0.99	0.976
Cooccurrence	0.69	1.99	**0.013**
PeriodT2	1.81	6.12	**<0.001**
PlantHydrilla	-2.84	0.06	**<0.001**
Conductivity	0.07	1.07	**<0.001**
ZDS	0.05	1.05	0.733
FlowLotic:PeriodT2	-1.26	0.28	**0.022**
FlowLotic:PlantHydrilla	2.81	16.56	**<0.001**
PlantHydrilla:ZDS	0.95	2.59	**<0.001**

In summary, the significant term PeriodT2 (Table 5) suggests that both plants increased the chance of occurrence in the second period. However, this increase is more expressive in lentic environments, since the interaction FlowLotic:PeriodT2 is significantly negative. Although lotic environments are important to *H. verticillata*, this species increased the odds of occurrence over time more expressively in lentic habitats (proportionally).

Another aspect favoring the occurrence of both species is the presence of a cooccurring plant. The term Cooccurrence was significantly positive (Table 5) suggesting that the presence of the other species favors the presence of the species evaluated on the same path (without distinction between species). That is, the effect of *H. verticillata* on *E. najas* is the same as the effect of *E. najas* on *H. verticillata*, once the interaction between Plant*Cooccurrence was not selected.

Regarding the remaining abiotic predictors, transparency (ZDS) was only important for *H. verticillata*, but not for *E. najas*, while conductivity was important for both.

2.4.3 Changes in lentic environments of Paraná Subsystem (PS)

Looking at the ZDS separately for PS lentic sites (Tables SM02 and SM03), we see that the water transparency for these environments was significantly higher in T2 ($F = 5.237$; $p = 0.02$) than T1 regardless of the month.

2.4.4 Exploring the cooccurrence of plants

The CPO_{it} values suggest that *H. verticillata* and *E. najas* cooccur more than expected by chance in the UPRF. We found values of CPO_{it} = 1.92, and it was higher than any randomly generated index.

2.5 Discussion

2.5.1 General perspectives

The invasion process and its costs and benefits related to invasive species management are context-dependent (Simberloff et al., 2013). In the case of UPRF, our results suggest that the monitoring and surveillance of the invasive *H. verticillata* seem to be the best strategy.

We found not enough evidence to affirm that *Hydrilla verticillata* is replacing the native *E. najas*. The invasive macrophyte seems to be still confined to the PS after 10 years of invasion. The only sample station we found this macrophyte established out of the PS was in one site in BS. However, this site was connected and very close to the PS shore (ca 300 m). No other site in BS and IS seems to offer suitable conditions for *H. verticillata* growth.

Considering the sites where *H. verticillata* and *E. najas* occur, we found no evidence *H. verticillata* affects the native macrophyte negatively. Indeed, the presence of the cooccurring plant was selected as a predictor of submerged macrophyte occurrence could indicate a facilitation interaction. Therefore, the native *E. najas* continue to be prolific and, maybe, positively impacted by the presence of *H. verticillata* occurrence. Not only, but *E. najas* seems to be affecting the invasive species in the same positive way (see *Cooccurrence of plants* section for a better discussion).

Combining our finding with the fact that the management of *H. verticillata* is very difficult and that is almost impossible to remove it from large water bodies such as PS, the best approach would be to keep monitoring the invasive macrophyte's behavior considering the potential environmental changes (see the section below). In other words, the invasiveness of *H. verticillata* in the UFPR has not increased so far since the evaluation made by Sousa et al. (2009), which otherwise would demand a management action.

2.5.2 Environmental features and changes demand surveillance

The fact of the odds of *H. verticillata* occurrences increased in lentic environments raises some questions worth to be investigated. Lentic environments such as lakes of the PS, are not suitable for *H. verticillata* colonization because they are usually less transparent and contains more organic matter in the sediment than lotic sites, which are harmful conditions to *H. verticillata* growth (Barko and Smart, 1983; 1986; Sousa et al. 2009; 2010, Silveira and Thomaz, 2015). Thus, some changes in these variables might be triggering the occurrences of *H. verticillata* in lentic environments. Although our study was not designed to evaluate the spectrum of the importance of each predictor, we could propose some explanations for these associations.

Looking at the entire data set (all periods and sites), water transparency (ZDS) was the most important predictor for *H. verticillata* occurrence (Table 5). Considering only the PS, where *H. verticillata* occurs, lentic sites of this subsystem showed higher ZDS in T2 than in T1 (Appendix B – Figure B2). Of course, we are comparing two snapshots of what is going on in the landscape. However, the history of impacts in the Paraná river by reservoirs indicates that this would be a matter of concern. The chain of reservoirs in this river has been responsible for increasing the ZDS and decrease the nutrient availability in the river channel (Agostinho et al., 2004; Roberto et al., 2009). If this process of "oligotrophization" is affecting lakes of PS in the same way, *H. verticillata* might become more frequent in the lentic environments of PS.

Indeed, the low frequency of *H. verticillata* in lentic environments so far seems to be related to a multivariate combination of water transparency, organic matter content in the sediment and water flow (Silveira, 2015). Silveira (2015) showed that *H. verticillata* could grow in lake sediment transplanted to lotic sites (more transparent with a high flow). Thus, increasing the water transparency could help the submerged plants to overcome the negative effects of other abiotic filters, such as organic matter, especially in areas of the lakes near the river channel (ca. 300 m). These sites contain less organic matter and suffer more impact from daily water level fluctuation, which decreases the anoxia of the sediment compared to other portions of the lakes away from the main river channel.

As pointed out by Sousa et al. (2009), ZDS alone does not explain why *H. verticillata* cannot establish in the PS lakes because these environments are usually shallow (c.a. max 2.5 m deep) with littoral zones large enough to enable sufficient underwater light above the photosynthetic compensation point. However, our results suggest an increase in water transparency may contribute more to *H. verticillata* occurrences than *E. najas* ones. Therefore, further experimental studies are necessary to understand the importance of the gradient and the interactions among ZDS and other predictors in the *H. verticillata* colonization success.

2.5.3 Hydrilla verticillata is not a threat to lentic habitats (yet)

Although the invasion of *H. verticillata* in lentic habitats of PS sounds like a threat to these highly diverse habitats (Agostinho et al., 2004), it does not seem to be so concerning. The probability of occurrence of *E. najas* also increased in both lotic and lentic environments in T2, which shows that the most frequent submerged native macrophyte in UPRF (Souza et al., 2017) is not being replaced by *H. verticillata* so far.

Considering the impacts from the reservoir in the UPRF, changes in the prevalence of both studied macrophytes should be continuously investigated because aquatic plants respond directly to the flood seasonality (Junk et al., 1989; Sousa et al., 2010). The artificial water level regulation caused by reservoirs decreases the frequency and the intensity of flood pulses (Agostinho et al., 2004), enabling lentic sites to be shallow and transparent for enough time to allow *H. verticillata* colonization. Indeed, we would expect a low probability of *H. verticillata* occurrence at the end of the flood season because of the damage (e.g., uprooting) caused by the flood pulse disturbance (Sousa et al., 2010). However, hydrology was not selected in the variable selection, making sense if no significant flood occurs and macrophytes could continue to grow without any significant damage. This seems to have happened during our samples in T1 and T2 (Appendix A -

Figure A1). In T1, there was no significant flood pulse in the sample performed in Apr 2008. Furthermore, there was a significant drought period in T2 with no flood pulse before our sampling (Appendix A – Figure A1). In summary, despite we found no significant threat from the invasive macrophyte, our findings highlight the need to surveillance the *H. verticillata* along with the impacts of reservoirs in the abiotic characteristics of UPRF, especially in lentic sites.

2.5.4 Cooccurrence of plants

The cooccurrence of a neighbor plant seems to increase the odds of occurrence of both plants studied here (Table 5). That is, the occurrence of *H. verticillata* seems to have a positive effect on the occurrence of *E. najas*, and the opposite is true. This is reinforced by CPO_{it} values indicating that both plants cooccur more than expected by chance in the UPRF.

In theory, a facilitation effect is possible between both plants. Below here we discuss some potential mechanisms that could explain this relationship. However, these hypotheses depend on further evidence from experiments to be supported.

Hydrilla verticillata is more resistant to mechanical ruptures than *E. najas* (Oliveira et al., 2019). The growth of *H. verticillata* patches in lotic environments, such as PS, could reduce the river flow in the inner portions of the patches creating suitable conditions for *E. najas* development. On the other way, biomass of submerged macrophytes, such as *E. najas* stabilizes the sediment contributing to the maintenance of clear water states in lentic sites.

This promotes n increased transparency in the water column, which is the main predictor of *H. verticillata.*

As highlighted by Sousa (2011), "before investing substantial effort to control Hydrilla, managers should weigh the potential costs and benefits of available techniques and consider the potential benefits of Hydrilla in providing ecosystem services". In terms of impacts in the UPRF, *H. verticillata* is problematic because of its high biomass which impairs fishing, recreational activities, and navigation (Sousa, 2011). However, considering ecological impacts, we found no displacement of the native species *E. najas*, and neutral or even positive impacts have been confirmed to other assemblages. For example, *H. verticillata* seems to favor small-sized fish assemblages as much as *E. najas* do at the UPRF (Cunha et al., 2011, Carniatto et al., 2014; Figueiredo et al., 2015). However, this invasive species seems to homogenize the Chironomidae species (Gentilin-Avanci et al., 2020).

In a "big picture", we show here that there is no reason for panic (yet) in terms of biotic interactions (evaluated here for *E. najas*). However, we used presence/absence data to investigate these interactions at a regional scale. Such investigations are scale-dependent and could be influenced by the type of measurement utilized. For example, Pulzatto et al. (2019) found the abundance of *E. najas* is associate with the decrease in *H. verticillata* biomass at a finer grain (quadrat). Therefore, further studies that consider e.g. *in situ* biomass are needed to evaluate the biotic interactions regarding *H. verticillata* and its impacts over time and in different grains.

2.6 Final remarks

Considering the anthropogenic impacts in the UFPR and the lags of time of decades to centuries in invasion processes (Crooks, 2011) the monitoring of *H. verticillata* should be continued. Furthermore, UPRF has a scenario where unexpected interactions among *H. verticillata* and other invasive species could lead to unexpected outcomes. For example, Michelan et al., (2014) found that *H. verticillata* facilitates the establishment of the golden mussel (*Lymnoperna fortunei*), in a reservoir of the UPRF. If *H. verticillata* biomass increases in UPRF lakes along with the golden mussel, the higher filtration rate of this mussel would increase the water transparency which would increase the colonization of *H. verticillata* in an invasional meltdown effect (Simberloff and Holle, 1999). Long Term Ecological Researches are crucial to understand this type of processes and the knowledge from the *H. verticillata* invasion on UPRF would be valuable to other RAMSAR sites invaded by this species.

We highlighted the need to further studies to understand the interactions between abiotic factors to elucidate the colonization of *H. verticillata* in lentic sites, and we also highlight the need for surveillance of potential abiotic changes over time in these sites of PS. We expect that our case study would help decision-makers at the UPRF and in other RAMSAR sites to choose better decisions.

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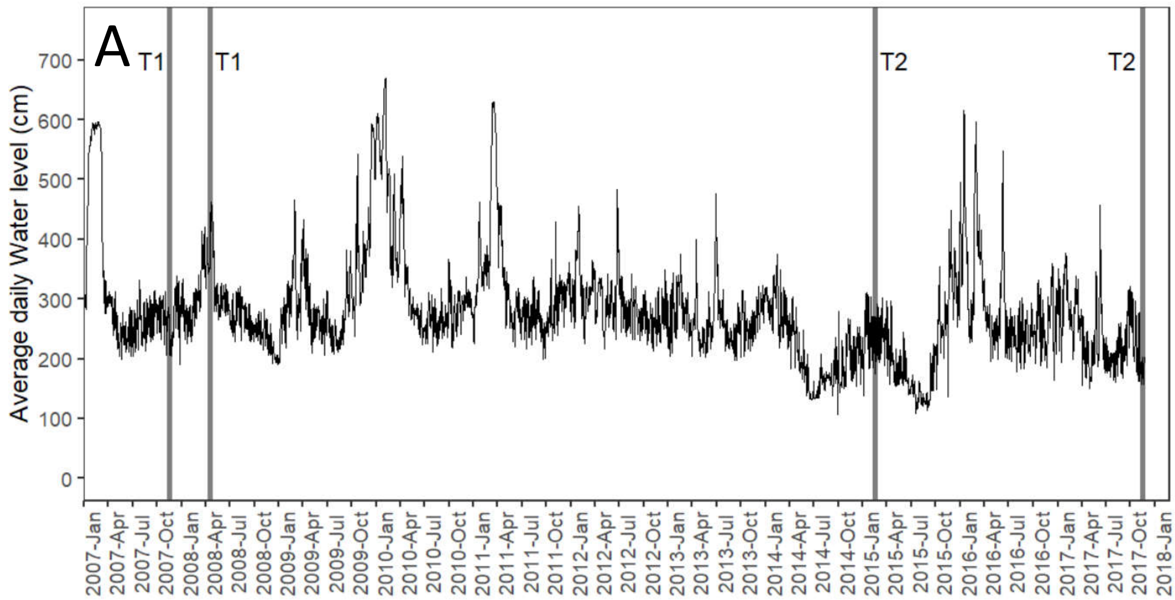
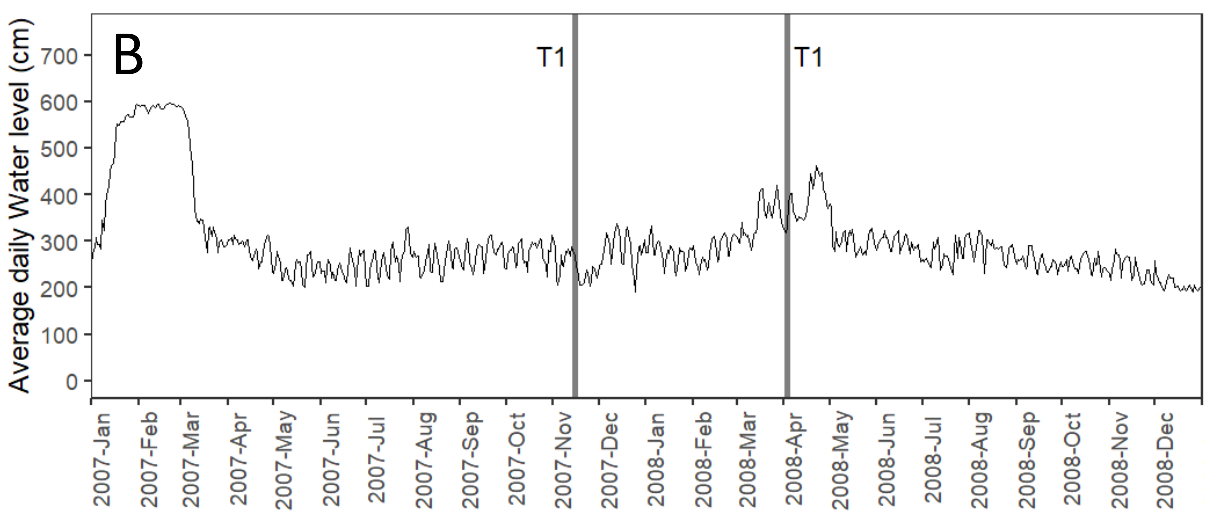
APPENDIX A –- Water level in Paraná river during sampling





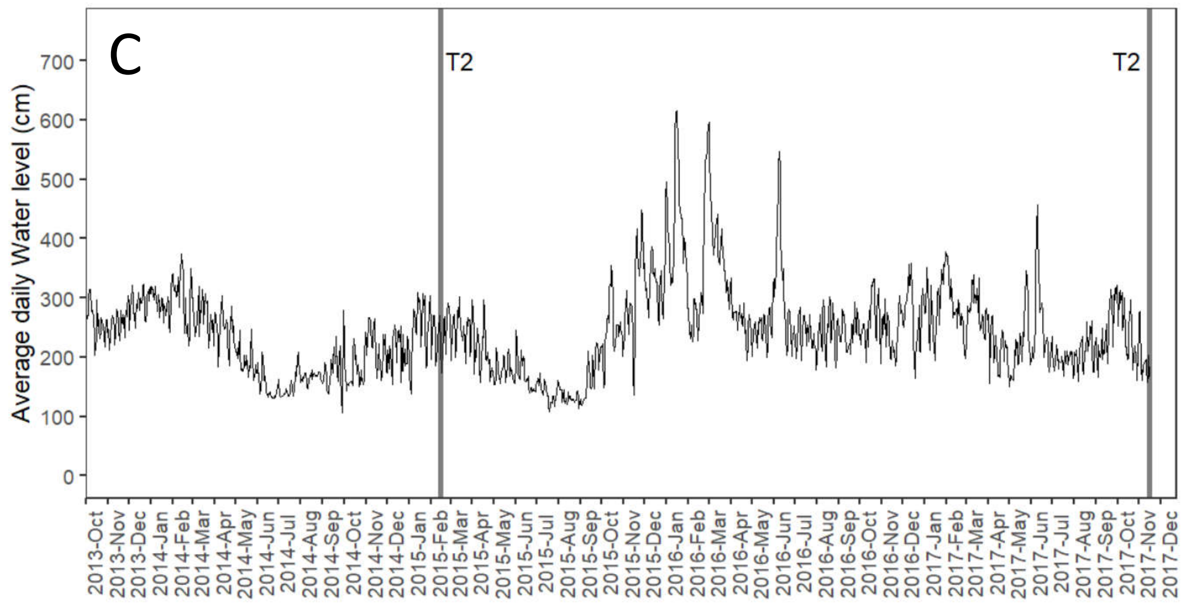


Figure A1 - Average daily water level (m). Vertical gray lines are referent to each sample taken in both periods: T1 (2007 and 2008) and T2 (2015 and 2017) - A. Beneath the entire period you can check the details for period T1 (Zoom T1) - B, and T2(Zoom T2) - C.

APPENDIX B - Checking changes in lentic sites in Parana subsystem

As *H. verticillata* seems to have increased the odds of occurrence in lentic sites of this subsystem, we filtered the dataset in order to compare the lentic environments between T1 and T2. We performed a two-way Anova for water transparency (Table C2) values. We set the period (T1 and T2) and the month (mes) as predictors. All assumptions were achieved.

Secchi increased significantly in T2 (see tables and graphs below).

Table B1 - Source of variation for the Anova analysis of Secchi for lentic environments in PS

	Df	Sum of Square	Mean Square	F	p-value
Period	1	2.51	2.51	5.23	**0.02**
Hydrology	1	0.29	0.29	0.61	0.43
Period:Hydrology	1	0.10	0.10	0.211	0.64
Residuals	33	15.805	0.47		

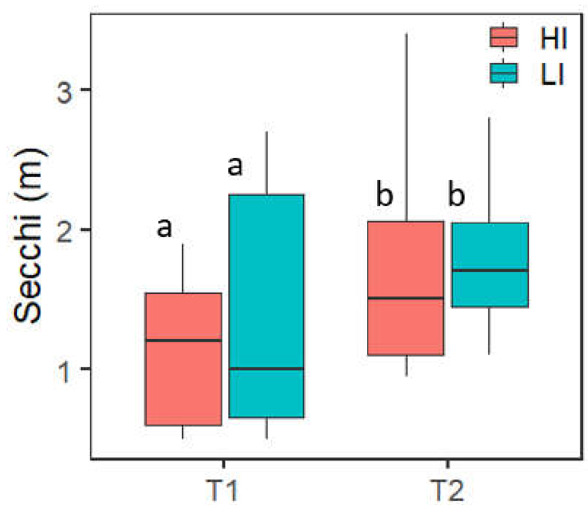


Figure B2 – Water transparency for lentic environments in Parana subsystem. Different letters are related to Tukey post hoc test. LI (low influence of flood pulse) corresponds to November, and HI (high influence of flood pulse) corresponds to Apr for T1 and Feb for T2.

APPENDIX C - Conductivity and ZDS (water transparency) during the samples

Table C2 – Mean and standard deviation (sd) of Conductivity and Water transparency (ZDS) in lentic and lotic sampling stations in each subsystems. Time 1 is referent to samples collected in 2007 and 2008, while T2 is related to the years 2015 and 2017. In each (T1 and T2) samples were taken in LI and HI– represented in different columns for each variable. LI (low influence of flood pulse) corresponds to November, and HI (high influence of flood pulse) corresponds to Apr for T1 and Feb for T2. NA standard deviation were not able to be calculated because there was only one value in this period (see methods).

Subsystem	Flow	Period	Conductivity_HI	Conductivity_LI	ZDS_HI	ZDS_LI
Baia	Lentic	time1	41.99 (15.85)	50.18 (5.9)	0.91 (0.29)	0.62 (0.46)
Baia	Lotic	time1	40.33 (12.71)	50.46 (1.96)	0.95 (0.37)	0.82 (0.24)
Ivinheima	Lentic	time1	62.47 (3.29)	58.85 (1.34)	0.57 (0.08)	0.48 (0.04)
Ivinheima	Lotic	time1	63.43 (1.56)	63.93 (0.42)	0.61 (0.02)	0.53 (0.06)
Parana	Lentic	time1	67.32 (2.86)	66.34 (6.72)	1.15 (0.52)	1.43 (0.94)
Parana	Lotic	time1	66.01 (4.44)	67.99 (6.92)	1.68 (0.42)	2.22 (1.65)
Baia	Lentic	time2	30 (3.61)	17.92 (4.66)	0.83 (0.06)	0.78 (0.34)
Baia	Lotic	time2	23 (2.45)	18.9 (3.51)	1.16 (0.23)	0.75 (0.25)
Ivinheima	Lentic	time2	42 (NA)	28.93 (3.06)	0.8 (NA)	0.48 (0.2)
Ivinheima	Lotic	time2	43 (1)	30.86 (2.19)	0.6 (0)	0.48 (0.06)
Parana	Lentic	time2	58.5 (2.73)	68.29 (3.77)	1.74 (0.83)	1.8 (0.57)
Parana	Lotic	time2	60 (6.29)	64.07 (7.7)	2.23 (1.11)	2.97 (1.13)

3 AQUATIC MACROPHYTE INVASIONS – A GLOBAL OVERVIEW OF OCCURRENCE AND PATHWAYS OF INTRODUCTION

ABSTRACT

Invasive aquatic macrophytes are concerning to freshwater ecosystems worldwide because of their capacity to influence hydrological, geomorphological, physical, and chemical characteristics of the environment and interaction with different organisms. In this study, we contributed to the knowledge about the flow of naturalized macrophyte species from their native range to the recipient ecosystems as well as the main pathways of introductions. Such knowledge is crucial to control and prevent species introductions. Considering a global approach, we compiled data from many databases to identify which regions are sources, which ones are recipients for naturalized macrophytes (and their life-forms), and the pathways for such introductions. In general, our finding highlighted a call for attention to the macrophyte invasions. Many regions of the world can provide potential macrophyte invaders and these invaders, at first, are more likely to use intentional pathways, which are easier to be managed, in theory. Intentional pathways must be prioritized because we also showed a considerable role of the "Unaided" pathway, which means that once introduced, macrophytes could spread easily via natural means. The majority of the naturalized macrophytes are emergent, which deserve further attention because these species could be introduced not targeting the aquatic environment, however, it could become harmful to this system.

Key words: Biological invasions; Freshwater; Aquatic vegetation; Pathways of introduction; Species distribution.

3.1 Introduction

For centuries, humans have been introducing organisms beyond their native range (Simberloff et al., 2013). Some of these introduced species can sustain self-replacing populations for many life cycles (naturalized species; Richardson et al., 2011). Depending on their population growth and spreading ability, some naturalized species can become invasive and pose a serious threat to biodiversity and ecosystem functioning (Blackburn et al., 2011; Richardson et al., 2011).

Due to the multifaceted impacts of naturalized species and the associated high costs of their eradication and control, avoidance and prevention of introductions are the best strategies for managing these organisms (Simberloff et al., 2013). Knowledge about the naturalized and native distribution of organisms allows identifying source and sink regions of naturalized species (Turbelin et al., 2017). In addition, an understanding of introduction pathways is crucial to guide political actions that prevent the unwanted movement of species (Hulme et al., 2008; Ells et al. 2015) since pathways describe the process that allows alien species to move from one geographic region to another (Richardson et al. 2011). Combining this information is pivotal to prevent future introductions and guide responses to current invasions (Hulme et al., 2008; CBD, 2014; Novoa et al., 2020).

Indeed, the identification and prioritization of invasive species and pathways of introduction were set as one of the Aichi Biodiversity Targets (target 9) in 2010, at the Convention on Biological Diversity (https://www.cbd.int/sp/targets/). Since then, scientists have compiled valuable information on the origins and pathways of introduced species in databases and data repositories (e.g., van Kleunen et al., 2019; CABI ISC, 2019). In addition, many studies have been carried out to gain information on the occurrence, pathways, and trait spectra of introduced species, which helps scientists to understand the general patterns of biological invasions (Pyšek et al., 2011; Essl et al., 2015; Saul et al., 2017; Turbelin et al., 2017; Novoa et al., 2020). Given the high diversity of introduced organisms and their impacts, decision-makers depend on the information that allows them to work on small scales focusing on specific species and specific problems. However, the work of managers is complicated because the field of invasion biology is highly idiosyncratic (Simberloff, 2010) and different combinations of plant traits, introduction pathways, and invaded systems result in different outcomes (Pyšek et al., 2011; Daehler, 2003; Novoa et al., 2020), which demand different management strategies and policies. There is a practical need to focus on specific systems and organisms to better understand invasion peculiarities and increase the power of prediction in invasion biology (Pyšek et al., 2011; Elliott-Graves, 2016; Novoa et al., 2020).

Freshwater ecosystems comprise the highest biodiversity per unit area on our planet (Dudgeon et al., 2006). Still, they are especially vulnerable to introductions because of their large spatial extents, the myriad of impacts imposed to them (e.g. dams, eutrophization, urbanization), and the nature of the processes related to these environments (García-Berthou & Moyle, 2011; Zedler, 2011). In addition, aquatic water bodies like rivers and rivers-floodplain ecosystems form corridors among habitats that can facilitate the dispersal of invasive species (Howell & Benson, 2000; Čuda et al., 2017). These ecosystems also feature natural disturbances associated with flooding, enhancing invasion success by reducing biotic resistance, providing establishment windows, and increasing resource supply (Barden, 1987; Toth, 2010, Davis et al., 2000).

Aquatic macrophytes have important ecological roles in freshwater ecosystems because they influence other aquatic communities and the ecosystem functioning (e.g., Bunn et al., 1998; Klančnik et al., 2018; O´Hare et al., 2018). However, several aquatic macrophyte species have traits that enhance invasiveness, such as high fragmentation and clonal gloth (Santamaría, 2002). Invasive aquatic macrophytes are troublesome because they reduce native species diversity and, consequently, affect organisms at high-trophic levels that use native macrophytes as food or shelter (Michelan et al., 2010; Simberloff & Rejmanek, 2011; Carniatto et al., 2013). Some invasive aquatic macrophytes can become ecosystem engineers, by transforming the key structure and functioning of an entire ecosystem (Yarrow et al., 2009). Such profound changes caused by invasive aquatic macrophytes can also lead to damage of infrastructure and economic losses. For example, invasive aquatic macrophytes can clog irrigation and water collection pipes and decrease energy production by clogging water from entering the turbines and reducing navigation areas. In total, it has been estimated that the spread and management of invasive species cost more than $100 million annually in the U.S., alone (Pimentel et al., 2005).

Aquatic macrophytes have different life-forms (e.g., submerged, emergent and free-floating; Sculthorpe, 1967) and thus, considering invasive species, each life-form causes a different impact on the ecosystem. For example, submerged species depend primarily on underwater radiation (Chambers and Kalff, 1985) and their impacts are related to underwater habitat structure and stability of a clear water state, for example (van Donk and van de Bund, 2002). Free-floating species depend on the nutrient content in the water column (Anderson, 2011). They can reduce the under-water light availability and impact the primary production and gases exchange with the atmosphere (Scheffer et al., 2003; Villamagna & Murphy, 2010; Hill et al., 2011). By comparison, the impact of emergent macrophytes extends from the shoreline towards the limnetic regions, e.g., it can silt up a river bench (Bunn et al., 1998).

Focusing the invasion process investigation on a single group, such as naturalized macrophytes, can disentangle the peculiarities of the invasion processes and propose better and feasible management actions. Understanding geographic sources, sinks, and pathways for macrophyte invasions could allow managers to scan for and intercept aquatic species that pose a potential risk. Furthermore, knowing what kind of life-forms (or functional groups) are associated with a specific pathway and a specific region could allow managers to predict the potential impacts of introduced aquatic plants in native ecosystems.

In this paper, we assembled and analyzed a global dataset to identify frequent pathways of introduction and geographic sources and sinks for the most common naturalized aquatic macrophytes. Efforts similar to ours have been made considering large groups of invasive organisms, e.g., all plants, all vertebrates, or all freshwater species (Pyšek et al., 2011; Essl et al., 2015; Saul et al., 2017; Turbelin et al., 2017). However, at our knowledge, we are the first to provide an overview of the prevailing life-forms among invasive aquatic macrophytes, potential species flow from native to naturalized regions and introduction pathways across geographical regions considering mainland and island areas.

3.2 Materials and Methods

We built a dataset containing a global species list of aquatic macrophytes, information on their naturalized range, their native range, pathways of introductions, and life-form (see appendices for further details or contact the corresponding author).

3.2.1 Species list

We combined different datasets to compile a global list of naturalized aquatic macrophytes. We started with a list provided by Murphy et al. (2019), which evaluated the world's distribution of aquatic macrophytes. To identify naturalized macrophytes, we filtered all species in Murphy et al. (2019) that are listed in the The Global Naturalized Alien Flora (GloNAF) database (van Kleunen et al., 2019) and checked all species in GloNAF that could be considered aquatic. The GloNAF database contains data of the occurrence and identity of alien naturalized vascular plants worldwide (van Kleunen et al., 2019). After these procedures, the species list included 815 naturalized species that can be considered aquatic, i.e., species that grow permanently or periodically submerged or floating (totally or partially) in water bodies (Chambers et al., 2008). This dataset mainly included macrophyte plants from freshwater ecosystems. However, we also included macrophyte species that can colonize both aquatic and non-aquatic environments, since these species can also invade freshwater ecosystems.

3.2.2. Naturalized and Native Range

Species native ranges were extracted from the Global Inventory of Floras and Traits (GIFT) (Weigelt, König and Kreft, 2019). GIFT is a global archive of regional plant checklists, floras and functional traits (Weigelt, König and Kreft, 2019). By considering the taxon-by-region combination provided by GloNAF and GIFT, we could trace geographic patterns in macrophyte introductions from native to naturalized ranges at consistent geographic levels. We considered only the equivalent regions between GIFT and GloNAF datasets. That is, regions that are delimited by the same polygons in both datasets. There are some cases where a species is considered native (GIFT) and naturalized (GloNAF) to the same region (region_id) given the uncertainty of the status of a species in a given area. We removed such entries to avoid biases. In summary, we were able to identify both the naturalized and native range for 641 (78%) out of the 815 species.

Both databases (GIFT and GloNAF) provide species distribution according to the World Geographical Scheme for Recording Plant Distribution (TDWG (Taxonomic Databases Working Group) - Brummitt et al., 2001), with some exceptions. For example, some species in GloNAF have an area of occurrence that covers more than one geographic unit according to the TDWG regions (van Kleunen et al., 2019). When multiple regions overlapped with each other, we merged the data into one single region, keeping the most regional level as possible, that is, the smallest polygon as possible to be considered a unit of record of species occurrences (Appendix A). The procedure avoids overcounting the number of species in a single region. For that reason, all New Zealand regions were considered a single region, and data related to Baja California and Baja California Sur in Mexico were merged.

Because Turkey is considered in the European and Asian continent, this region is included in GloNAF in continent level called Mixed. The response variables for this level are not shown in the boxplots for aesthetic purposes. Instead, they are reported separately on figure captions.

3.2.3. Pathways of introduction

We used Saul et al. (2017) as a primary source for classifying pathways of introduction. These authors combined information from different databases and standardized it according to the Convention on Biological Diversity (CBD, 2014).

To complement the data, we retrieved information from other data sources not considered by Saul et al. (2017). We mined data from the Invasive Species Compendium (CABI ISC, 2019) using web scraping techniques with the *rvest* package (Wickham, 2019) in the R environment (R Core Team 2020). We also used data from the European Alien Species Information Network (EASIN) (Katsanevakis et al., 2015).

By the time we collected the data, neither CABI ISC nor EASIN pathways were standardized according to CBD (2014) framework. For this reason, we converted the causes and vectors of introductions present on CABI ISC (2019) to pathway categories and subcategories (CBD, 2014) using the general descriptions of each cause and vector and, if information was necessary and available, using the notes for each species recorded in CABI

ISC (2019) (Appendix B). Regarding the EASIN database, pathway categories were converted into the CBD framework following Tsiamis et al. (2017) guidelines.

The pathways comprised the following categories: Release in nature; Escape from confinement; Transport - Stowaway & Contaminant; Corridor and Unaided (CBD, 2014). All pathways' categories have subcategories to specify the pathway of introduction, except for the "Unaided" category. Hence, we included the "Unaided" category among other subcategories to facilitate comparisons of pathways frequency. In total, we were able to compile information on pathways of invasion (categories and subcategories) for 277 species on our species list (33%).

3.2.4. Life-forms

Aquatic macrophytes life-form is a general trait that describes different ways of plants to explore the environment. We used life-forms categories as defined by previous studies (e.g. Lukács et al., 2017; Schneider et al., 2018) and assigned them to species based on descriptions and images from floras, databases, biodiversity portals, and published articles to provide a life-form classification (Table 1) using the same strategy as Schneider et al. (2018) (Appendix C).

Table 1

Life-form categories assigned to aquatic macrophytes (based on Schneider et al. 2018)

Life-form	Characteristics
Emergent	Roots in the sediment and stems and leaves above the water surface.
Rooted floating-stemmed	Roots in the sediment and stems spread over the water surface
Rooted floating-leaved	Roots in the sediment, petioles reaching the water surface and floating leaf blades
Free-floating	Roots in the water column and leaves floating above the water surface
Free submerged	Roots in the water column and the entire body freely beneath the water surface
Root submerged	Roots in the sediment with underwater stems and leaves
Epiphytic	Roots above other plants and stems and leaves above water

We assigned some species to more the one category. For example, *Brachiaria arrecta* (T. Durand & Schinz) Stent can develop roots in the shore of aquatic bodies as a typical "emergent" species (Table 1), and it is also able to extend its stems toward limnetic regions behaving like a "rooted floating-stemmed" (Table 1) (Michelan et al., 2010; Boschilia et al., 2012).

3.2.5. Data analysis

Tracking the geographic origin and introduction pathways is quite difficult for most species, relying on genetic studies and historical data for each naturalized species. In that sense, we analyzed our final dataset considering the potential regions that donate species (native range) to the region in which these species have been introduced (naturalized range) and the potential pathways related to those introductions. Thus, we considered pathways of introduction as a species trait, i.e., the pathway that a species can be introduced by in somewhere else than its native range.

To identify which regions are the sources and sinks of invasive macrophytes, we calculated the Kappa index (as used by Turbelin et al., 2017):

$$K = 10\frac{S'Inv - S'Nat}{S'Inv + S'Nat}$$

where “S’Inv” is the total number of naturalized macrophyte species in a given region divided by the total number of naturalized macrophytes species recorded in our dataset (641). S’Nat is the number of species native in a given region but invasive somewhere else, divided by the total number of recorded species in our dataset (614). The result is multiplied by 10 (arbitrary value) to provide a range from -10 to +10 which indicates whether the given region is a source or a sink of naturalized species. A negative value of K means that the region contains more native species that are introduced elsewhere than it is suffering introduction, i.e. this region is working as a source of species that are introduced elsewhere. In other words, Kappa index shows the balance between the ingress/egress of naturalized macrophyte species in a particular region.

Data manipulation and visualization procedures were made with the tidyverse package (Wickham et al., 2019). To avoid mismatches in different databases, species names were standardized according to The Plant List using the package Taxonstand (Cayuela et al., 2019). Maps were generated using the shapefile provide by GloNAF (van Kleunen et al., 2019).

3.3 Results

Here we highlighted the general trends of our findings, however, we strongly recommend the reader (especially decision-makers and managers) to request our full dataset to understand patterns related to specific regions of interest. Some regions at TDWG 4 levels have the same name but represents different polygons (e.g. Seychelles). Readers can check the supplementary material and GloNAF shapefile (van Kleunen et al., 2019) to search for specific regions and polygons.

3.3.1. Distribution and Flow of Naturalized Species

We report here results for 197 countries (937 regions). New Zealand was the region with the highest number of naturalized macrophytes species followed by Japan, North American and Australasia regions (Fig. 1, Table 2). Considering the area of each region, islands had the highest number of naturalized species per km² (Table 2) with Seychelles and Australia also achieving high ranks on the list (Table 2).

In general, the amplitude of the number of naturalized species on islands (136) is higher than in mainland regions (94), and the difference increases when we compare the species-area ratio for islands (43.7) and mainland regions (0.344). In all cases, the minimum value was 0.

Table 2 - Top 10 regions ranked according to the number of naturalized species in each region (upper section) and according to the species-area ratio (bottom section). Regions are named according to the TDWG scheme (Brummitt et al., 2001) level 4. Country names are extracted from GloNAF database. N. of Species is the count of naturalized species in each region; Spec./Area is the ratio between the number of naturalized species and the area (in km^2) of each polygon (van Kleunen et al., 2019). Type column identifies island and mainland regions. Region column shows the identity of each area (polygon) in the dataset. All regions in New Zealand were treated as a unique level.

Regions ranked considering the absolute number of naturalized species				
TDWG4 Region	**Country**	**N. of Species**	**Type**	**Region**
New Zealand	New Zealand	136	Island	All
Japan	Japan	112	Island	416
Florida	United States of America	94	Mainland	745
Victoria	Australia	88	Mainland	107
California	United States of America	77	Mainland	740
Hawaiian Is.	United States of America	74	Island	748
Hawaiian Is.	United States of America	74	Island	762
Queensland	Australia	70	Mainland	81
New South Wales	Australia	68	Mainland	55
New South Wales	Australia	66	Mainland	59
Regions ranked considering the species-area ratio				
TDWG4 Region	**Country**	**N. of Species/km^2**	**Type**	**Region**
Seychelles	Seychelles	43.71	Island	707
Western Australia	Australia	14.71	Island	71
Samoa	Samoa	11.73	Island	815
Samoa	Samoa	8.32	Island	814
Seychelles	Seychelles	8.16	Island	705
Samoa	Samoa	8.08	Island	816
Fiji	Fiji	6.07	Island	334
American Samoa	American Samoa	5.74	Island	29
Seychelles	Seychelles	4.80	Island	683
Seychelles	Seychelles	4.61	Island	692

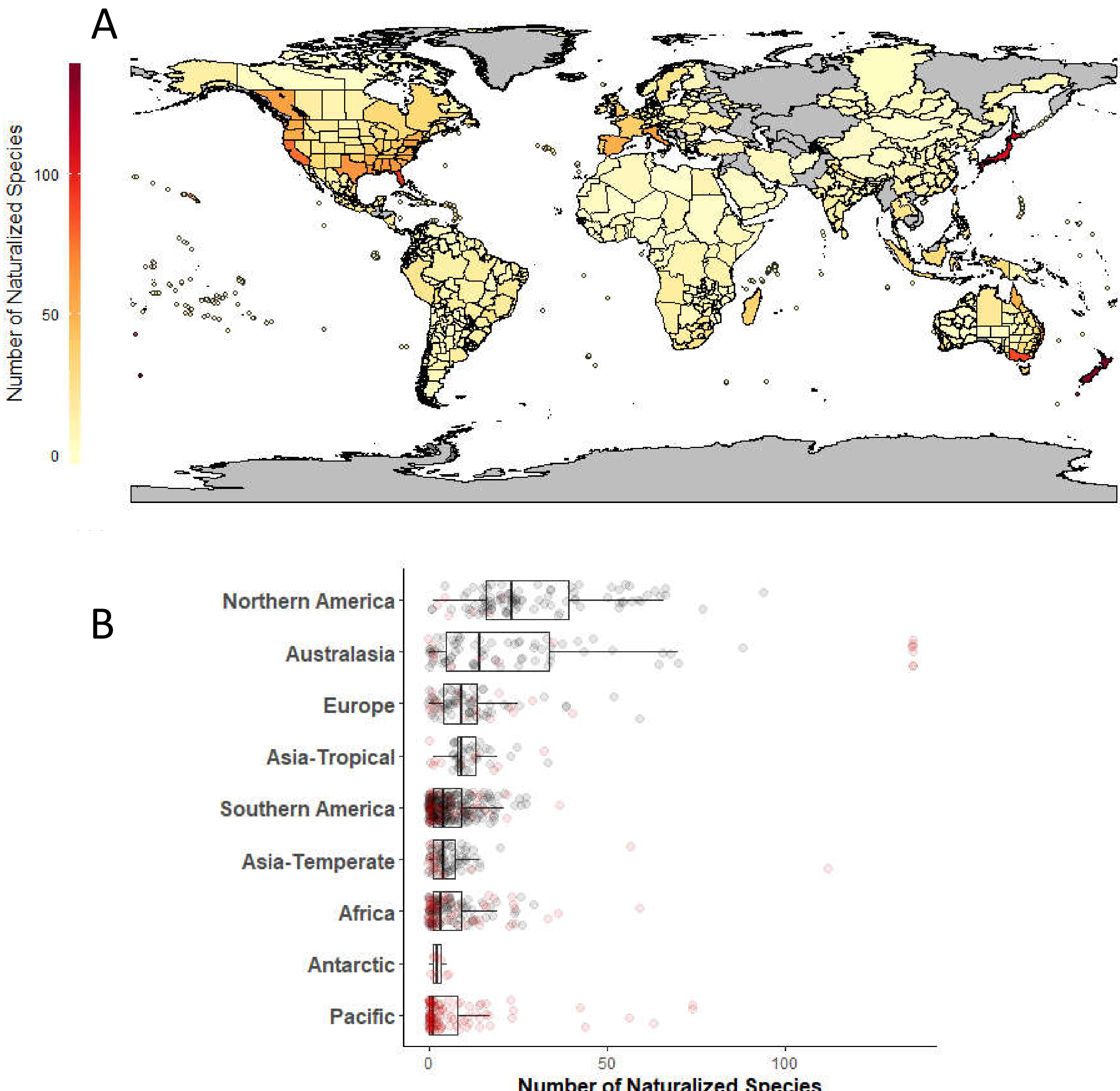


Fig. 1. (**A**) Global map of the number of naturalized aquatic macrophytes per region. Gray areas are permanent ice sheets or areas with lack of data; (**B**) Absolute Number of

Naturalized Species per continent (TDWG level 1). Total species n = 641. Each dot is referent to a specific region inside the continent (areas with a lack of data are not included). Grey dots = mainland; Red dots = islands. The Mixed level comprises only Turkey and it was omitted from the boxplot for aesthetical purposes (Number of Naturalized Species = 13).

In general, Europe has the higher numbers of native species of aquatic macrophytes that are naturalized elsewhere (Fig. 2). Along with European regions, South and North America contain the highest number of native species of macrophytes naturalized elsewhere (Appendix D - Table D1). Looking at the species-area ratio, Saychelles (Africa), Samoa islands (Pacific), and Macau (Asia-Temperate) were on the top of the list (Table 2).

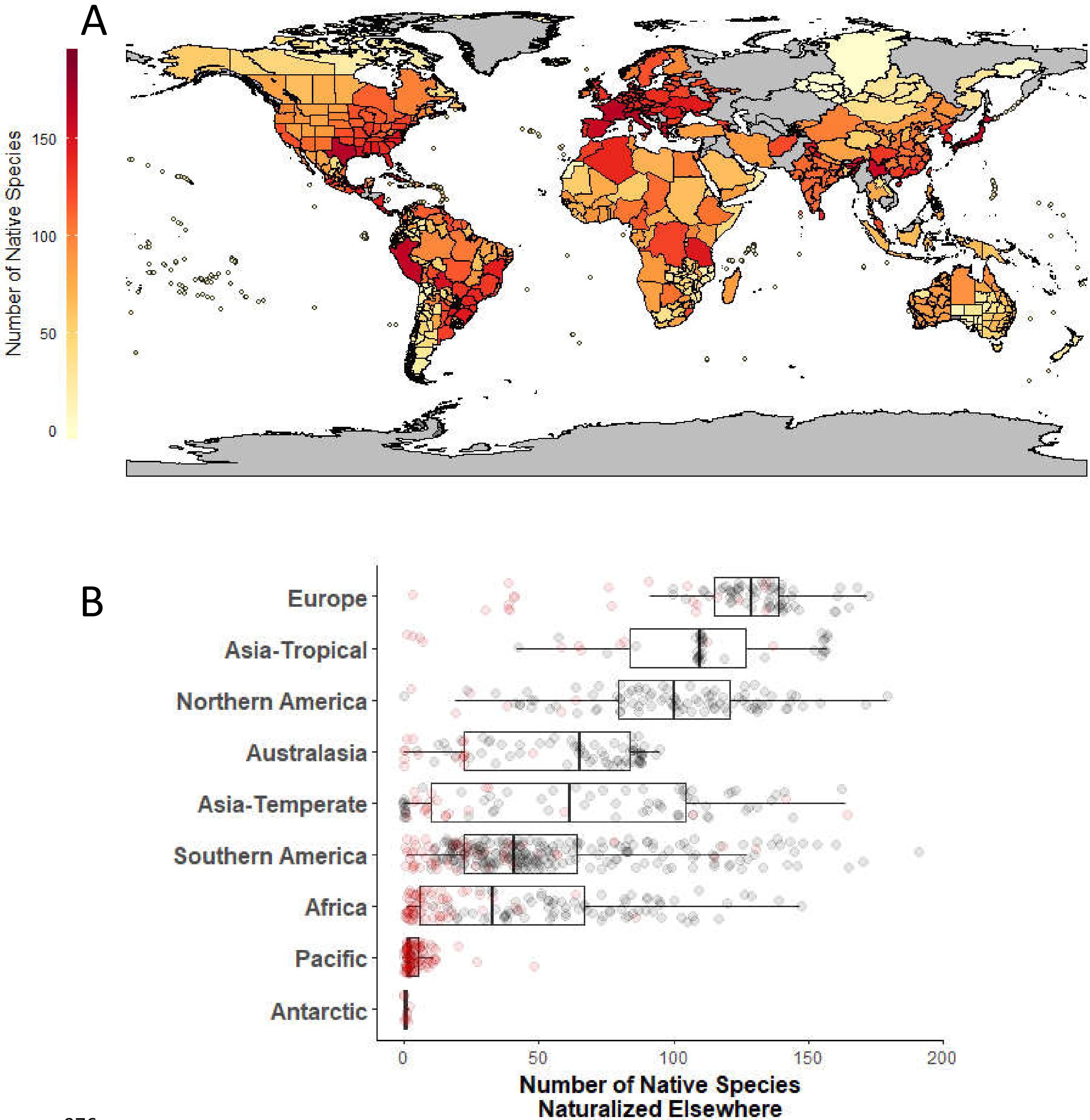


Fig. 2. (**A**) Global map of the number of native species of aquatic macrophytes per region that are naturalized elsewhere. Gray areas are permanent ice sheets or areas with a lack of data; (**B**) Absolute number of native species that are naturalized elsewhere, per region and

per continent (TDWG level 1). Total species n = 641. Each dot is referent to a specific region inside the continent (areas lacking data are not included). Grey dots = mainland; Red dots = islands. The Mixed level comprises only Turkey and it was omitted from the boxplot for aesthetical purposes (Number of Native Species = 87).

Taking the balance between the number of naturalized species in a region and the number of species native to that region that are naturalized elsewhere, we can see the regions that are working as sources or sinks of naturalized species (Fig. 3A). All European regions had negative Kappa values (Fig. 3B), indicating they are exporting more native species that became naturalized elsewhere than receiving introductions (source of naturalized species). All other regions are distributed between negative and positive values of Kappa (Fig. 3B); however, most regions can be considered as potential sources of macrophyte species that became introduced elsewhere. The majority of regions with Kappa > 0 are islands (83.3%), while most regions with negative values are continents (72.6%). Asia-Temperate regions, such as Tajikistan and Russia Federation are exceptions (Fig. 3).

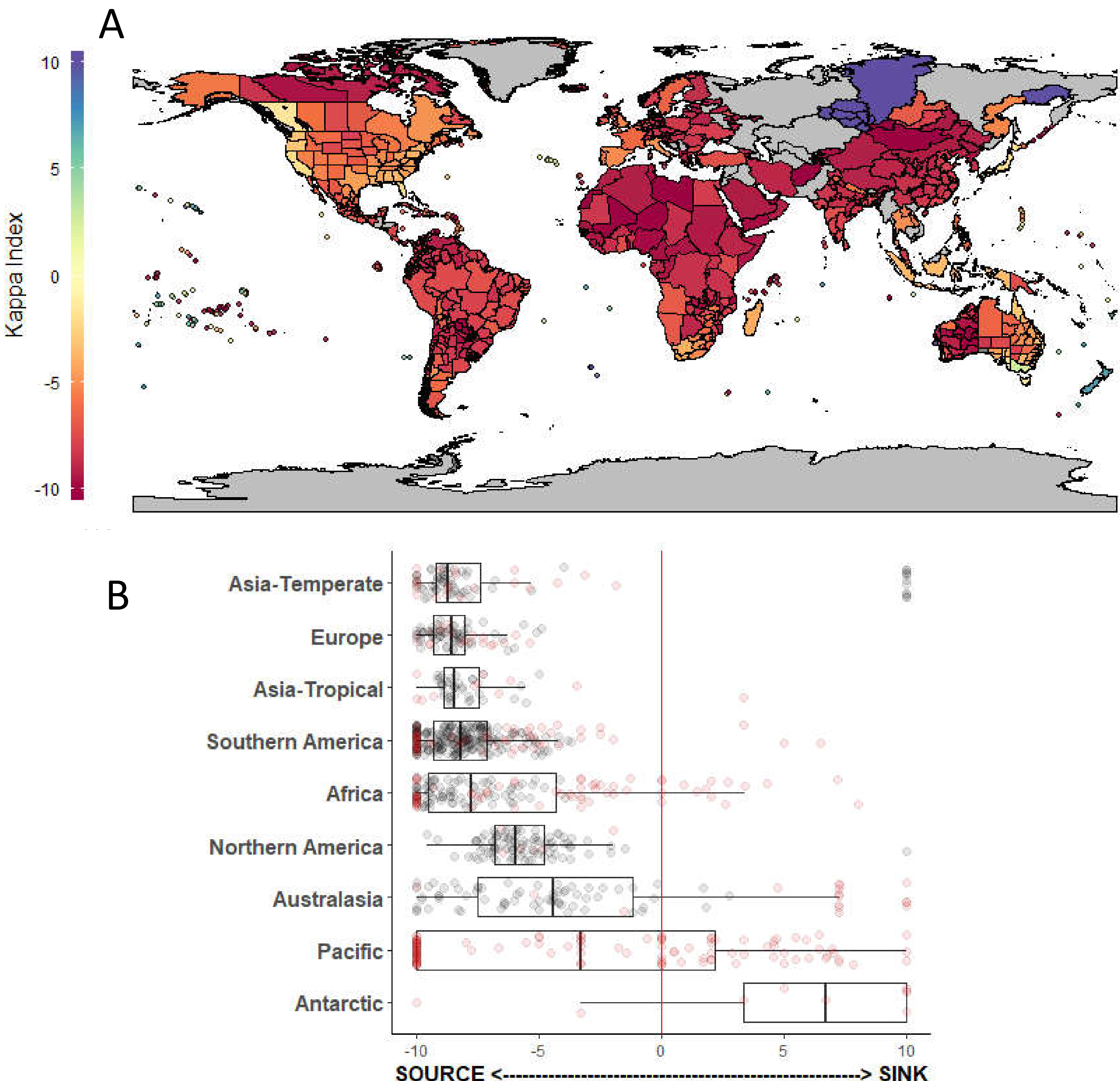


Fig. 3. (**A**) Kappa index showing the balance between the ingress/egress of macrophyte species in a particular region. Regions with negative values of Kappa index (yellow to red) act as a potential source of naturalized species, i.e. contain more native species that are

naturalized elsewhere than suffer introductions from foreign species. Gray areas are permanent ice sheets or areas without available data. Gray areas are permanent ice sheets or areas with lack of data; (**B**) Kaapa index per continent (TDWG level 1). Total species n = 641. Each dot is referent to a specific region inside the continent (areas with a lack of data are not included). Grey dots = mainland; Red dots = islands. The Mixed level comprises only Turkey and it was omitted from the boxplot for aesthetical purposes (Kappa = -7.4).

3.3.2. Pathway of introductions

The main pathway of introduction for most of the 277 species for which we found information was related to an escape following introductions due to ornamental purposes, horticulture, or usage as pet/aquarium/terrarium species (Fig. 4). Release in nature was the second most important pathway followed by the Unaided category, which refers to natural dispersal across borders. For those species introduced via transportation, most of the introductions seem to correlate to contaminated commodities, vehicles, and transportation of habitat material. Corridor was the less numerous pathways of introduction.

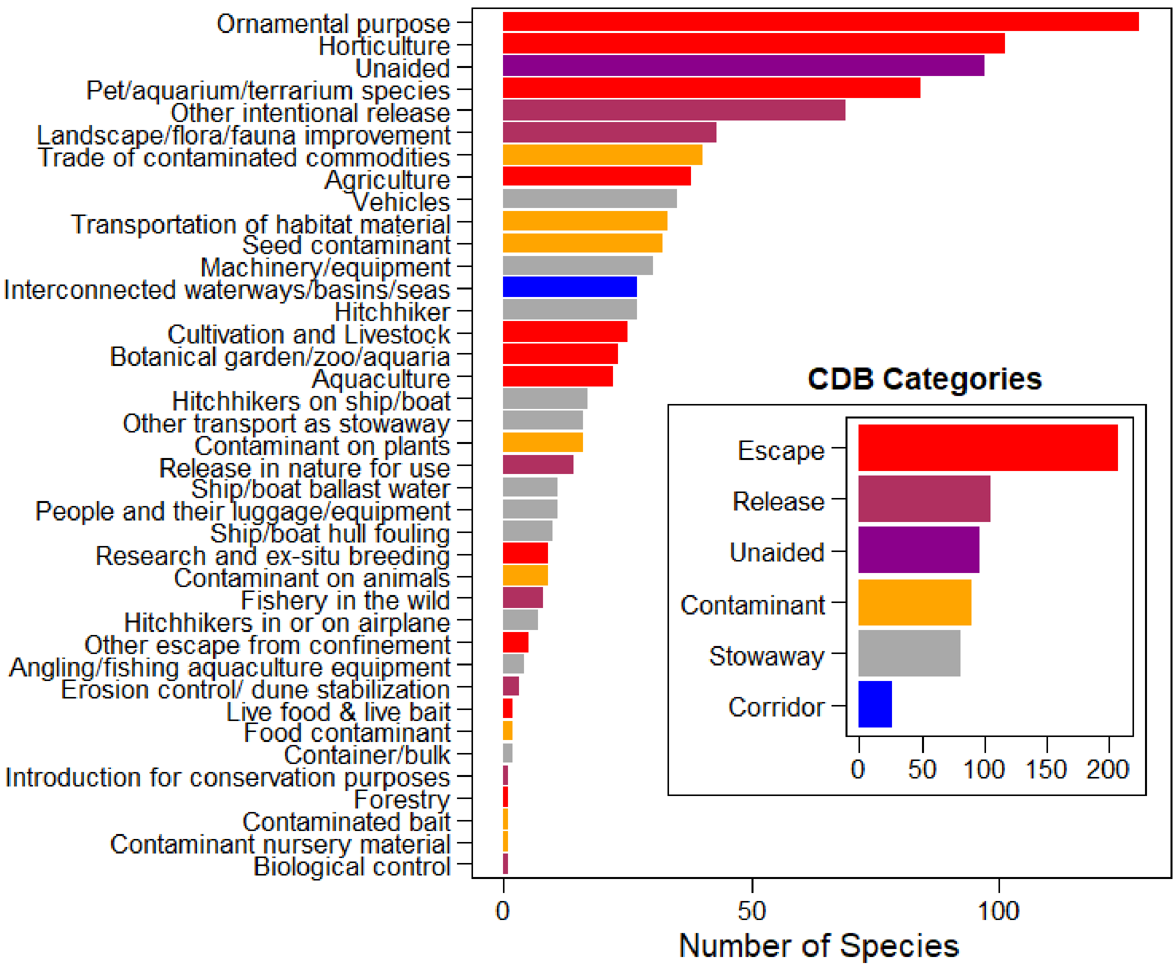


Fig. 4. Subcategories (main plot) and categories (sub plot) of the pathway of introductions. Bar sizes are referent to the number of species (unique entries) fitted in each category. A single species can be introduced via more than one pathway.

3.3.3. Life-form

The highest number of naturalized macrophyte species belongs to the emergent life-form, followed by rooted submerged and rooted floating-leaved species (Fig. 5A). We also found a higher number of subcategories of pathways among species belonging to these life-forms (Fig. 5B). Also, most of the species with the highest number of introductions in the world are emergent (Table 3).

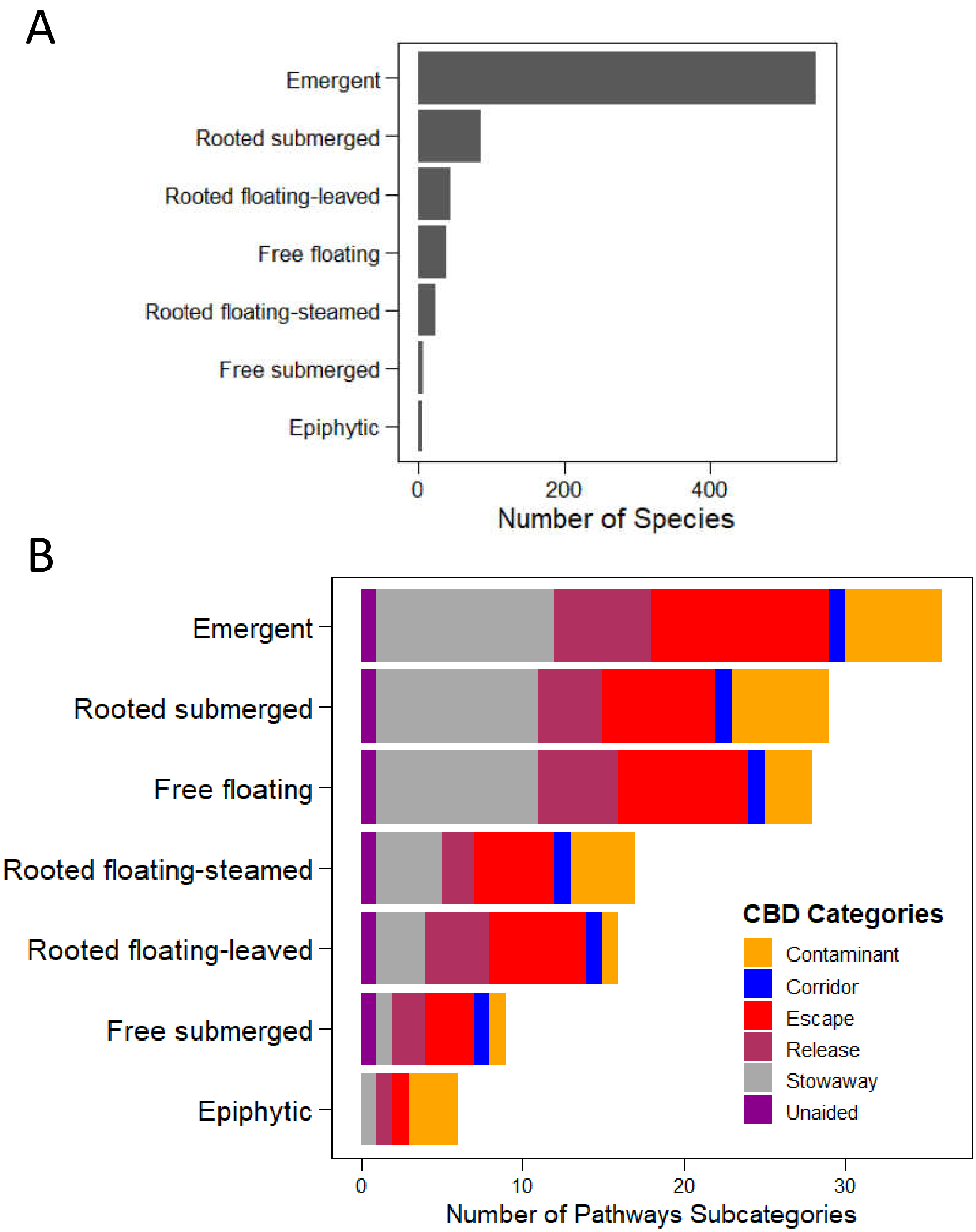


Fig. 5. Number of naturalized species of each macrophyte life-form (**A**) considered in this study. Number of subcategories of pathways among life-forms (n = 277 species) (**B**). Note that Unaided category does not have subcategories, that is way there is only one observation per life-form.

Among the naturalized species present in our dataset, *Salvinia molesta* (free-floating, synonym of *Salvinia adnata*), *Eichhornia crassipes* (free-floating), *Aruno donax* (emergent) and *Lythrum salicaria* (emergent) are present in the 100 of the World's Worst Invasive Alien Species list (Global Invasive Species Database, 2020). *Eichhornia crassipes* and *A. donax* also appear among the species with the highest number of introductions (Table 3).

Table 3
Top 10 introduced species ranked based on the number of different regions that each species is considered naturalized. Bold species names are among the IUCN 100 worst invasive species list.

Species	**Introductions**	**Life-form**
Panicum maximum	238	Emergent
Nasturtium officinale	238	Emergent
Eichhornia crassipes	232	Free-floating
Arundo donax	204	Emergent
Echinochloa crus-galli	196	Emergent
Echinochloa colona	185	Emergent
Agrostis stolonifera	163	Emergent
Mentha spicata	145	Emergent
Cyperus rotundus	139	Emergent\ Epiphytic
Brachiaria mutica	137	Emergent

3.4 Discussion

3.4.1 Distributions

According to the introduction–naturalization–invasion continuum, most introductions do not succeed because most species or populations that are transiting between geographic regions are not able to overcome the reproductive and ecological barriers in the new range and hence do not become naturalized (Richardson et al., 2006; Blackburn et al., 2011). Therefore, it is reasonable for the overall number of native macrophytes in a given region to be higher than the number of introduced species and thrived in this region. It is worth highlighting that the high number of naturalized species found for example in North America, Australia, and Japan represents a general biogeographical bias in the field of invasion biology (Pyšek et al. 2008). It coincides with the fact that these regions have complete naturalized species inventories compared to other regions, such as some Russian regions (van Kleunen et al., 2019), where we found high values of Kappa index. Thus, increasing the efforts in cataloging naturalized species in regions with poor inventories may impact the results found here (see van Kleunen et al., 2019 for an evaluation of naturalized plant inventories).

Despite the possible bias, some patterns found here seem to follow general patterns that have been reported for the total naturalized alien flora on the globe (van Kleunen et al., 2015). European regions contain the highest number of native species that are naturalized elsewhere. In addition, no European region had Kappa > 0, which indicates that European regions are among the main donors of naturalized species. Because of European colonialism and the activity of acclimatization societies, European plants have been introduced in many places around the globe and propagated through human settlement and development (van Kleunen et al., 2015). Indeed, Europe and Temperate Asia have been reported as the main donors of naturalized vascular plants, in general (van Kleunen et al., 2015) and this pattern seems to pertain to naturalized macrophytes, too.

Another interesting pattern is that most of the regions with positive values of Kappa (i.e., sink regions of invasive macrophyte species) are islands. Islands have been considered to have higher invasibility than similarly sized mainland regions, which is related to the available niche spaces not occupied by native species (Denslow, 2003, Kleunen et al. (2015), Dawson et al. 2017). Van Kleunen et al. (2015) provided the first empirical evidence of this statement for naturalized plants. Here, we showed this trend is also true when we look at naturalized macrophyte species. Counterintuitively, oceanic islands contain fewer areas of freshwater environments than mainland regions, limiting the occurrence of macrophytes that only colonize habitats covered by water or very close to it. However, we considered species that occur across a range of aquatic and non-aquatic environments, which may have contributed to these findings.

It is essential to highlight that our findings do not reflect the distribution of all macrophytes, only those considered naturalized somewhere, for which we explored the native and naturalized range. There are controversies regarding the broad (Santamaría, 2002; Chambers et al., 2008) and/or the narrow distribution range of macrophytes (Murphy et al., 2019). However, high plasticity and a wide native range attributed to naturalized macrophyte species seem to best explanation for our results.

We found that most regions function as potential sources of naturalized macrophyte species. This might be related to the fact that some species, especially the most frequent invaders have a wide native range. For example, *Panicum maximum* Jacq., one of the most common introduced plant worldwide, has a native distribution that encompasses, in part, most of Africa, the Arabic peninsula, and some localities in Europe. That is, many regions could have functioned as a source region of *P. maximum* to other regions where the species is not native. In addition, this species can tolerate a wide range of environmental conditions, once it can occur in African as well as European regions under different climate conditions. The same is true for *Nasturtium officinale* R.Br., which has a native range in Africa, Europe, Asia-Temperate, Northern and Southern America. These two species, which are the most frequently introduced species (Table 3), highlight two mains points about macrophytes invaders: i) high plasticity to tolerate different environments across a high latitudinal gradient in their native range, and ii) a high number of native regions that can export these macrophytes elsewhere.

The number of introductions shows which species have become naturalized, and thus it indicates the potential of species to become invaders regardless of the impact that they would promote after their introduction. The implications of our findings are based on the number of species and the number of introductions that a species showed in different regions, not on the "impact" of these introductions. The notion of impact and the importance of an introduction are context- and species-dependent (Vilà et al., 2011; Novoa et al., 2020). However, the number of introductions in a given area is one of the main metrics used to build concern lists as is the case of the 100 worst invasive species (Luque et al., 2014). To illustrate this reasoning, *Salvinia molesta* and *Lythrum salicaria* are among the 100 worst species in the IUCN list and they are among the top 20 species with a high number of introductions in our dataset.

Since we evaluated only naturalized species, there is evidence that these species are capable of maintaining self-sustainable populations in the introduced area. Therefore, they are potential candidates to become invasive species in regions where they are not introduced yet. Our findings suggest that more areas in the world could act as a source of macrophyte species with the potential to be naturalized elsewhere than sinks of naturalized species. Given the high number of aquatic macrophyte naturalizations worldwide, it is important that alien macrophyte species are considered a high-risk group in alien species regulation and management.

3.4.2 Introduction pathways

Propagule pressure is one of the key factors in determining introduction success (Williamson & Fitter, 1996 e Colautti et al., 2006; Simberloff, 2009; Duncan, 2011). This term encompasses the "quantity, quality, composition and rate of supply of alien organisms resulting from the transport conditions and pathways between source and recipient regions" (Richardson et al., 2011). Because propagules rely on means to move between geographical regions, pathways play a crucial role in propagule pressure (Simberloff, 2009).

We found information about pathways for ca. 34% of all species; however, these species are among the most frequently naturalized species according to our dataset. For example, ca. 80% of the top 100 species with the high numbers of introductions have information about pathways. Thus, although our discussion about pathways represents only a part of all macrophyte naturalizations, it refers to the most concerning species.

Most naturalized species in our dataset have been introduced by pathways of intentional introductions, via "Escape from confinement" and "Release in nature" (Saul et al., 2017). In general, "Escape from confinement" plays a major role in plant invasions (Saul et al., 2017; Turbelin et al., 2017), and this is not different for naturalized macrophytes. Because of its ornamental characteristics, macrophytes species are appreciated by enthusiasts of aquaria and gardens and thus, it is not surprising that "Ornamental", "Horticulture" and "Pet commerce" constitute the majority pathways among study species that we analyzed (Hamel and Parsons, 2001; Cohen et al., 2001; Champion et al., 2010; Azan et al, 2015; Peres et al., 2018). Furthermore, when looking at macrophyte naturalized species, we found higher participation of the "Release in nature" pathway than other studies which evaluated pathways for all plants or all freshwater species (Pyšek et al., 2011; Saul et al., 2017). The release of macrophytes in nature may enhance the establishment and naturalization of these plants due to the high invasiveness of macrophytes, associated with the existence of several plant structures that helps spreading, like seeds, turions, rhizomes and mainly plant fragments (Fleming and Dibble., 2015). These sexual and asexual propagules typical of macrophytes encounter the favourable environment for spreading in the water median, through hydrochory, ichthyochory and other means of dispersion (Anderson, 2011), which enhances establishment success.

In theory, intentional introductions are easier to regulate and prevent than accidental introductions (Hulme et al., 2008). This means that legislation on macrophyte introductions needs to be created for administrative regions that lack respective frameworks and tightened in areas that have existing regulations.

The “Unaided” pathway is considered underestimated (Hulme et al., 2008, Saul et al., 2017) and is difficult to be interpreted because dispersal barriers are species-specific (Essl et al., 2015). Combining different datasets, we found a higher number of naturalized macrophyte species related to the “Unaided” pathway. This category does not have subcategories, and it is related to the secondary dispersal of species that have been introduced by other pathways (CBD, 2014). Similarly to what we discussed earlier for the “Release in Nature” pathway, attributes of macrophytes, such as stress-tolerant taxa with prolific clonal growth and, usually, long-distance dispersal of sexual propagules and high local dispersion of asexual propagules (Santamaría, 2002; Fleming and Dibble, 2015), seems to justify the high number of species related with this particular pathway. For example, the submerged macrophyte *Hydrilla verticillata* (L.f.) Royle invaded a reservoir in a Brazilian subtropical floodplain in 2005 probably by aquarium trade - “Escape from confinement” (Sousa, 2011). A few years later, this species could spread more than 300 km downstream in a reservoir at the border of Brazil and Paraguay (Thomaz et al., 2009, Sousa, 2011). Thus, our results suggest that once introduced, macrophytes could be easily passively dispersed and introduced elsewhere. The same reasoning is applied to “Corridors”, but this pathway seems to be the less important, maybe because it does not involve direct human transportation (Hulme et al., 2008) and it depends on a huge infrastructure that makes it less frequent than other pathways. However, the efficiency of corridors in carrying aquatic plants is high (Hulme et al., 2008), and then not negligible.

The results we found here that macrophyte species could also be introduced via transportation as a stowaway and/or contaminant, is following previous studies (see Brundu, 2015 and references therein). For example, invasive macrophyte species can be easily attached to boats and boat trailers, a major overland dispersal vector for invasive aquatic plants (Johnstone et al., 1985; Rothlisberger et al., 2010; Bruckerhoff et al., 2015). Even submerged macrophyte species can tolerate sufficient air exposure to be transported and introduced into new areas (Bickel, 2015; Bruckerhoff et al., 2015).

3.4.3 Life-forms

Most naturalized macrophytes belong to the emergent life-form. Emergent species, such as the broad-range genera *Cyperus* L. (Cyperaceae) and *Brachiaria* (Trin.) Griseb. (Poaceae) colonize aquatic and non-aquatic (but moist) environments (Murph et al., 2019) which contributes to their high invasiveness allowing them to be introduced in more diversified ways than other life-forms, such as free submerged or epiphytic (Fig. 5). This explains why the most introduced macrophytes species are emergent (Table 3) except for the water hyacinth (*E. crassipes*). However, there is a bias related to the fact that the Emergent life-form naturally contains a higher diversity of species than other life-forms (e.g., Souza et al., 2017; Schneider et al., 2018; Oliveira and Bove, 2016).

Life-forms can be an approximate predictor for the ecological impacts macrophytes can have on the recipient ecosystem because they represent different ways these organisms influence the environment (Sculthorpe, 1967). Since most of the naturalized macrophytes are emergent, decision-makers must pay attention to problems related to this life-form (e.g., silting up). However, as mentioned earlier, the specific impacts of an introduced species are species- and context-dependent, and thus, potential impacts of other life-forms should be considered wherever is a source and a sink of naturalized macrophytes and pathways linking them.

3.5 Conclusion

We highlight the call for attention to the macrophyte invasions. We showed that many regions of the world can act as sources for naturalized alien macrophytes and that these species, at first, are more likely to use intentional pathways which are easier to be managed. These pathways must be prioritized because we also showed huge participation of the "Unaided" pathway, which means that once introduced, macrophytes could spread easily via natural means.

As most macrophytes that become naturalized are emergent, this life-form needs further attention because this species could be introduced both via aquatic and non-aquatic pathways. We hope our study helps decision-makers to manage and prevent macrophyte introductions.

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APPENDIX A - Incongruences with native vs naturalized range

Combining GloNAF and GIFT regions, we ended up having some species that was considered native and naturalized to the same TDWG4 level. In these cases, we remove these problematic entries to avoid biases. By doing that, 116 were removed from the dataset.

Glonaf dummy regions overlaps with multiple TDWG regions

For some references in Glonaf dataset there are data at a country level only. Thus, authos created regions that overlap multiple TDWG regions (see van Kleunen et al., 2019 data set descriptors). For that reason, I’ve checked all potentials overlaps.

We fond 10 regions with potential problems:

region_id: 368 370 394 416 446 525 673 818 889 921

Procedures to check overlaps:

1. Filter the countries which have dummy regions;
2. Extract dummy regions within each country;
3. Visually check plots with and without the dummy region
4. Search for the specific intersection using the sf::st_intersection() function;
5. The decision to merge regions was made based on the proximity and the polygons that was overlapped by the dummy region.

India

- Region 370: Independent from other regions
- Region 394: GloNAF does not have the IND-PO, IND-KL, IND-YA. Instead they have a region 000-09 to cover these regions. Readers interested in these regions must be aware of this.

Indonesia

- Ok. The dummy region is unique to the dataset

Japan

- Ok. The dummy region is unique to the dataset

Mexico

- Region_id: 446. This region overlaps regions 923 and 924. I merged this three regions into one: region_id 446 and then count the number of unique entries (species) for this region. For those who want details about separate regions they can check the region_id column. Remember that those species records for region 446 covers all area of 923 and 924.

New Zealand

- The dummy region region_id 525 cover almost all other polygons. I merged all information about New Zealand at a country level.

Papua New Guinea

- Ok. The dummy region is unique to the dataset

Sao Tome and Principe

- Ok. The dummy region is unique to the dataset

Turkey

- Ok. The dummy region is unique to the dataset

Yemen

- Ok. The dummy region is unique to the dataset

APPENDIX B – Pathways of introduction

Note: Readers can request to the corresponding author the full data set and all scripts regarding data manipulation and analysis.

Table B1 - Each species name (standardized_name) is standardized according to The Plant List (http://www.theplantlist.org/). Pathways categories (CDB_category) and subcategories (CDB_subcategory) are standardized according to the Convention on Biological Diversity (https://www.cbd.int/doc/meetings/sbstta/sbstta-18/official/sbstta-18-09-add1-en.pdf).

standardized_name	**CDB_category**	**CDB_subcategory**
Marsilea mutica	Escape from confinement	Ornamental purpose
Marsilea quadrifolia	Escape from confinement	Ornamental purpose
Marsilea quadrifolia	Escape from confinement	Horticulture
Azolla caroliniana	Escape from confinement	Ornamental purpose
Azolla caroliniana	Escape from confinement	Horticulture
Azolla filiculoides	Transport - Contaminant	Transportation of habitat material
Azolla filiculoides	Escape from confinement	Horticulture
Azolla filiculoides	Escape from confinement	Ornamental purpose
Azolla filiculoides	Release in nature	Landscape/flora/fauna improvement
Azolla filiculoides	Escape from confinement	Botanical garden/zoo/aquaria
Azolla filiculoides	Escape from confinement	Pet/aquarium/terrarium species
Azolla mexicana	Escape from confinement	Ornamental purpose
Azolla pinnata	Escape from confinement	Pet/aquarium/terrarium species
Azolla pinnata	Escape from confinement	Agriculture
Azolla pinnata	Transport - Contaminant	Contaminant on animals
Salvinia adnata	Escape from confinement	Pet/aquarium/terrarium species
Salvinia adnata	Escape from confinement	Botanical garden/zoo/aquaria
Salvinia adnata	Transport - Stowaway	Hitchhikers on ship/boat
Salvinia adnata	Escape from	Horticulture

	confinement	
Salvinia auriculata	Corridor	Interconnected waterways/basins/seas
Salvinia auriculata	Escape from confinement	Pet/aquarium/terrarium species
Salvinia auriculata	Escape from confinement	Ornamental purpose
Salvinia auriculata	Escape from confinement	Horticulture
Salvinia auriculata	Escape from confinement	Aquaculture
Salvinia auriculata	Escape from confinement	Botanical garden/zoo/aquaria
Salvinia auriculata	Release in nature	Biological control
Salvinia auriculata	Release in nature	Other intentional release
Salvinia auriculata	Escape from confinement	Other escape from confinement
Salvinia auriculata	Transport - Stowaway	Hitchhiker
Salvinia auriculata	Transport - Stowaway	People and their luggage/equipment
Salvinia auriculata	Transport - Stowaway	Other transport as stowaway
Salvinia auriculata	Transport - Stowaway	Vehicles
Salvinia auriculata	Transport - Stowaway	Machinery/equipment
Salvinia auriculata	Transport - Stowaway	Ship/boat ballast water
Salvinia auriculata	Transport - Stowaway	Hitchhikers on ship/boat
Salvinia auriculata	Unaided	Unaided
Salvinia minima	Corridor	Interconnected waterways/basins/seas
Salvinia minima	Escape from confinement	Aquaculture
Salvinia minima	Escape from confinement	Pet/aquarium/terrarium species
Salvinia minima	Escape from confinement	Research and ex-situ breeding
Salvinia minima	Release in nature	Other intentional release
Salvinia minima	Transport - Stowaway	Hitchhiker
Salvinia minima	Transport - Stowaway	Machinery/equipment
Salvinia minima	Transport - Stowaway	Hitchhikers in or on airplane
Salvinia minima	Transport - Stowaway	Hitchhikers on ship/boat
Salvinia minima	Unaided	Unaided
Salvinia minima	Transport -	Contaminant nursery material

	Contaminant	
Salvinia minima	Transport - Stowaway	Ship/boat ballast water
Salvinia minima	Escape from confinement	Ornamental purpose
Salvinia natans	Escape from confinement	Ornamental purpose
Salvinia natans	Release in nature	Landscape/flora/fauna improvement
Salvinia natans	Escape from confinement	Pet/aquarium/terrarium species
Salvinia natans	Release in nature	Other intentional release
Ceratopteris thalictroides	Escape from confinement	Pet/aquarium/terrarium species
Ceratopteris thalictroides	Release in nature	Landscape/flora/fauna improvement
Ceratopteris thalictroides	Release in nature	Other intentional release
Ceratopteris thalictroides	Escape from confinement	Ornamental purpose
Acorus calamus	Escape from confinement	Horticulture
Acorus calamus	Escape from confinement	Ornamental purpose
Acorus calamus	Release in nature	Landscape/flora/fauna improvement
Acorus gramineus	Escape from confinement	Pet/aquarium/terrarium species
Acorus gramineus	Release in nature	Other intentional release
Alisma plantago-aquatica	Escape from confinement	Horticulture
Echinodorus cordifolius	Escape from confinement	Pet/aquarium/terrarium species
Helanthium bolivianum	Escape from confinement	Pet/aquarium/terrarium species
Limnocharis flava	Transport - Contaminant	Contaminant on animals
Limnocharis flava	Escape from confinement	Horticulture
Limnocharis flava	Escape from confinement	Botanical garden/zoo/aquaria
Limnocharis flava	Escape from confinement	Agriculture
Limnocharis flava	Escape from confinement	Ornamental purpose
Limnocharis flava	Escape from confinement	Pet/aquarium/terrarium species
Limnocharis flava	Escape from confinement	Research and ex-situ breeding
Limnocharis flava	Release in nature	Landscape/flora/fauna improvement
Limnocharis flava	Release in nature	Release in nature for use
Limnocharis flava	Transport - Contaminant	Transportation of habitat material

Limnocharis flava	Transport - Contaminant	Contaminant on plants
Limnocharis flava	Transport - Stowaway	Vehicles
Limnocharis flava	Transport - Stowaway	Container/bulk
Limnocharis flava	Unaided	Unaided
Limnocharis flava	Transport - Contaminant	Food contaminant
Limnocharis flava	Transport - Contaminant	Seed contaminant
Sagittaria graminea	Escape from confinement	Ornamental purpose
Sagittaria latifolia	Escape from confinement	Horticulture
Sagittaria latifolia	Escape from confinement	Ornamental purpose
Sagittaria latifolia	Transport - Contaminant	Contaminant on plants
Sagittaria latifolia	Unaided	Unaided
Sagittaria latifolia	Release in nature	Landscape/flora/fauna improvement
Sagittaria latifolia	Release in nature	Other intentional release
Sagittaria latifolia	Escape from confinement	Pet/aquarium/terrarium species
Sagittaria montevidensis	Escape from confinement	Ornamental purpose
Sagittaria montevidensis	Release in nature	Other intentional release
Sagittaria montevidensis	Escape from confinement	Pet/aquarium/terrarium species
Sagittaria platyphylla	Escape from confinement	Ornamental purpose
Sagittaria platyphylla	Escape from confinement	Pet/aquarium/terrarium species
Sagittaria platyphylla	Escape from confinement	Horticulture
Sagittaria rigida	Escape from confinement	Ornamental purpose
Sagittaria rigida	Release in nature	Other intentional release
Sagittaria rigida	Escape from confinement	Pet/aquarium/terrarium species
Sagittaria subulata	Release in nature	Landscape/flora/fauna improvement
Sagittaria subulata	Escape from confinement	Pet/aquarium/terrarium species
Sagittaria subulata	Release in nature	Other intentional release
Sagittaria trifolia	Escape from confinement	Horticulture
Aponogeton distachyos	Escape from confinement	Horticulture
Aponogeton distachyos	Escape from	Ornamental purpose

	confinement	
Aponogeton distachyos	Release in nature	Other intentional release
Aponogeton distachyos	Escape from confinement	Cultivation and Livestock
Aponogeton madagascariensis	Escape from confinement	Pet/aquarium/terrarium species
Caladium bicolor	Escape from confinement	Horticulture
Caladium bicolor	Escape from confinement	Botanical garden/zoo/aquaria
Caladium bicolor	Escape from confinement	Ornamental purpose
Caladium bicolor	Release in nature	Release in nature for use
Caladium bicolor	Transport - Stowaway	Other transport as stowaway
Calla palustris	Escape from confinement	Ornamental purpose
Cryptocoryne beckettii	Escape from confinement	Pet/aquarium/terrarium species
Cryptocoryne walkeri	Escape from confinement	Pet/aquarium/terrarium species
Cryptocoryne wendtii	Escape from confinement	Pet/aquarium/terrarium species
Cryptocoryne wendtii	Release in nature	Other intentional release
Lemna minor	Escape from confinement	Horticulture
Lemna minor	Escape from confinement	Ornamental purpose
Lemna minuta	Escape from confinement	Pet/aquarium/terrarium species
Lemna minuta	Unaided	Unaided
Lemna minuta	Escape from confinement	Ornamental purpose
Lemna minuta	Release in nature	Other intentional release
Lemna perpusilla	Corridor	Interconnected waterways/basins/seas
Lemna perpusilla	Escape from confinement	Pet/aquarium/terrarium species
Lemna perpusilla	Escape from confinement	Ornamental purpose
Lemna perpusilla	Escape from confinement	Horticulture
Lemna perpusilla	Escape from confinement	Aquaculture
Lemna perpusilla	Escape from confinement	Botanical garden/zoo/aquaria
Lemna perpusilla	Release in nature	Fishery in the wild
Lemna perpusilla	Release in nature	Landscape/flora/fauna improvement
Lemna perpusilla	Escape from confinement	Other escape from confinement

Lemna perpusilla	Transport - Stowaway	Hitchhiker
Lemna perpusilla	Transport - Stowaway	Machinery/equipment
Lemna perpusilla	Transport - Stowaway	Hitchhikers on ship/boat
Lemna perpusilla	Unaided	Unaided
Lemna turionifera	Release in nature	Other intentional release
Lemna turionifera	Escape from confinement	Ornamental purpose
Lemna valdiviana	Release in nature	Other intentional release
Lysichiton camtschatcensis	Escape from confinement	Agriculture
Lysichiton camtschatcensis	Escape from confinement	Horticulture
Lysichiton camtschatcensis	Escape from confinement	Ornamental purpose
Orontium aquaticum	Escape from confinement	Horticulture
Orontium aquaticum	Release in nature	Other intentional release
Orontium aquaticum	Escape from confinement	Ornamental purpose
Orontium aquaticum	Escape from confinement	Pet/aquarium/terrarium species
Pistia stratiotes	Escape from confinement	Horticulture
Pistia stratiotes	Escape from confinement	Aquaculture
Pistia stratiotes	Escape from confinement	Ornamental purpose
Pistia stratiotes	Escape from confinement	Pet/aquarium/terrarium species
Pistia stratiotes	Release in nature	Other intentional release
Pistia stratiotes	Release in nature	Landscape/flora/fauna improvement
Pistia stratiotes	Transport - Stowaway	Hitchhiker
Pistia stratiotes	Transport - Stowaway	Ship/boat ballast water
Pistia stratiotes	Unaided	Unaided
Pistia stratiotes	Transport - Stowaway	Angling/fishing aquaculture equipment
Pistia stratiotes	Transport - Stowaway	Ship/boat hull fouling
Spirodela oligorrhiza	Escape from confinement	Ornamental purpose
Spirodela punctata	Escape from confinement	Agriculture
Spirodela punctata	Escape from confinement	Ornamental purpose

Spirodela punctata	Escape from confinement	Pet/aquarium/terrarium species
Butomus umbellatus	Escape from confinement	Horticulture
Butomus umbellatus	Escape from confinement	Botanical garden/zoo/aquaria
Butomus umbellatus	Transport - Stowaway	Ship/boat ballast water
Blyxa japonica	Escape from confinement	Ornamental purpose
Blyxa japonica	Escape from confinement	Pet/aquarium/terrarium species
Egeria densa	Transport - Contaminant	Transportation of habitat material
Egeria densa	Escape from confinement	Horticulture
Egeria densa	Escape from confinement	Ornamental purpose
Egeria densa	Release in nature	Landscape/flora/fauna improvement
Egeria densa	Escape from confinement	Botanical garden/zoo/aquaria
Egeria densa	Escape from confinement	Pet/aquarium/terrarium species
Egeria densa	Release in nature	Other intentional release
Elodea callitrichoides	Escape from confinement	Ornamental purpose
Elodea callitrichoides	Release in nature	Landscape/flora/fauna improvement
Elodea callitrichoides	Release in nature	Other intentional release
Elodea canadensis	Escape from confinement	Pet/aquarium/terrarium species
Elodea canadensis	Escape from confinement	Ornamental purpose
Elodea canadensis	Escape from confinement	Aquaculture
Elodea canadensis	Release in nature	Fishery in the wild
Elodea canadensis	Transport - Stowaway	Hitchhiker
Elodea canadensis	Transport - Stowaway	Vehicles
Elodea canadensis	Transport - Stowaway	Ship/boat hull fouling
Elodea canadensis	Unaided	Unaided
Elodea canadensis	Release in nature	Landscape/flora/fauna improvement
Elodea canadensis	Transport - Stowaway	Ship/boat ballast water
Elodea canadensis	Escape from confinement	Botanical garden/zoo/aquaria
Elodea canadensis	Escape from confinement	Horticulture

Elodea canadensis	Transport - Contaminant	Contaminant on animals
Elodea canadensis	Release in nature	Other intentional release
Elodea nuttallii	Escape from confinement	Ornamental purpose
Elodea nuttallii	Escape from confinement	Pet/aquarium/terrarium species
Elodea nuttallii	Unaided	Unaided
Elodea nuttallii	Release in nature	Landscape/flora/fauna improvement
Elodea nuttallii	Release in nature	Other intentional release
Hydrilla verticillata	Transport - Contaminant	Contaminant on animals
Hydrilla verticillata	Escape from confinement	Pet/aquarium/terrarium species
Hydrilla verticillata	Transport - Contaminant	Contaminant on plants
Hydrilla verticillata	Transport - Stowaway	Ship/boat hull fouling
Hydrilla verticillata	Unaided	Unaided
Hydrilla verticillata	Escape from confinement	Ornamental purpose
Hydrilla verticillata	Release in nature	Landscape/flora/fauna improvement
Hydrocharis morsus-ranae	Corridor	Interconnected waterways/basins/seas
Hydrocharis morsus-ranae	Escape from confinement	Pet/aquarium/terrarium species
Hydrocharis morsus-ranae	Escape from confinement	Ornamental purpose
Hydrocharis morsus-ranae	Escape from confinement	Botanical garden/zoo/aquaria
Hydrocharis morsus-ranae	Escape from confinement	Horticulture
Hydrocharis morsus-ranae	Release in nature	Other intentional release
Hydrocharis morsus-ranae	Transport - Stowaway	Hitchhiker
Hydrocharis morsus-ranae	Transport - Stowaway	Vehicles
Hydrocharis morsus-ranae	Transport - Stowaway	Hitchhikers on ship/boat
Hydrocharis morsus-ranae	Unaided	Unaided
Lagarosiphon major	Corridor	Interconnected waterways/basins/seas
Lagarosiphon major	Escape from confinement	Pet/aquarium/terrarium species
Lagarosiphon major	Escape from confinement	Ornamental purpose
Lagarosiphon major	Escape from confinement	Aquaculture
Lagarosiphon major	Escape from confinement	Horticulture
Lagarosiphon major	Release in nature	Other intentional release

Lagarosiphon major	Transport - Stowaway	Hitchhiker
Lagarosiphon major	Transport - Stowaway	Vehicles
Lagarosiphon major	Transport - Stowaway	Hitchhikers in or on airplane
Lagarosiphon major	Transport - Stowaway	Hitchhikers on ship/boat
Lagarosiphon major	Unaided	Unaided
Lagarosiphon major	Release in nature	Landscape/flora/fauna improvement
Limnobium laevigatum	Escape from confinement	Aquaculture
Limnobium laevigatum	Escape from confinement	Ornamental purpose
Limnobium laevigatum	Escape from confinement	Pet/aquarium/terrarium species
Limnobium laevigatum	Transport - Stowaway	Hitchhikers on ship/boat
Limnobium laevigatum	Unaided	Unaided
Najas gracillima	Transport - Contaminant	Seed contaminant
Najas gracillima	Transport - Contaminant	Trade of contaminated commodities
Najas graminea	Transport - Contaminant	Seed contaminant
Najas graminea	Transport - Contaminant	Trade of contaminated commodities
Najas guadalupensis	Release in nature	Other intentional release
Najas marina	Transport - Contaminant	Trade of contaminated commodities
Najas minor	Escape from confinement	Pet/aquarium/terrarium species
Najas minor	Escape from confinement	Botanical garden/zoo/aquaria
Najas minor	Transport - Stowaway	Ship/boat hull fouling
Najas minor	Transport - Stowaway	Vehicles
Ottelia alismoides	Escape from confinement	Ornamental purpose
Ottelia alismoides	Release in nature	Other intentional release
Ottelia alismoides	Escape from confinement	Pet/aquarium/terrarium species
Stratiotes aloides	Escape from confinement	Ornamental purpose
Vallisneria americana	Escape from confinement	Pet/aquarium/terrarium species
Vallisneria nana	Escape from confinement	Pet/aquarium/terrarium species
Vallisneria nana	Release in nature	Other intentional release

Vallisneria spiralis	Escape from confinement	Pet/aquarium/terrarium species
Vallisneria spiralis	Unaided	Unaided
Vallisneria spiralis	Escape from confinement	Horticulture
Vallisneria spiralis	Escape from confinement	Ornamental purpose
Vallisneria spiralis	Release in nature	Landscape/flora/fauna improvement
Vallisneria spiralis	Release in nature	Other intentional release
Hydrocleys nymphoides	Escape from confinement	Horticulture
Potamogeton crispus	Corridor	Interconnected waterways/basins/seas
Potamogeton crispus	Escape from confinement	Pet/aquarium/terrarium species
Potamogeton crispus	Escape from confinement	Ornamental purpose
Potamogeton crispus	Escape from confinement	Horticulture
Potamogeton crispus	Escape from confinement	Aquaculture
Potamogeton crispus	Release in nature	Fishery in the wild
Potamogeton crispus	Release in nature	Release in nature for use
Potamogeton crispus	Transport - Stowaway	Hitchhiker
Potamogeton crispus	Transport - Stowaway	Hitchhikers in or on airplane
Potamogeton crispus	Transport - Stowaway	Hitchhikers on ship/boat
Potamogeton crispus	Unaided	Unaided
Potamogeton crispus	Transport - Stowaway	Ship/boat hull fouling
Potamogeton nodosus	Unaided	Unaided
Potamogeton perfoliatus	Escape from confinement	Pet/aquarium/terrarium species
Potamogeton perfoliatus	Transport - Stowaway	Hitchhikers on ship/boat
Potamogeton perfoliatus	Escape from confinement	Horticulture
Potamogeton perfoliatus	Transport - Stowaway	Machinery/equipment
Iris sibirica	Escape from confinement	Horticulture
Iris sibirica	Escape from confinement	Ornamental purpose
Iris spuria	Escape from confinement	Ornamental purpose
Iris pseudacorus	Escape from confinement	Ornamental purpose
Iris pseudacorus	Escape from	Horticulture

	confinement	
Iris pseudacorus	Release in nature	Erosion control/ dune stabilization
Iris versicolor	Escape from confinement	Ornamental purpose
Iris versicolor	Escape from confinement	Horticulture
Commelina benghalensis	Escape from confinement	Ornamental purpose
Commelina communis	Escape from confinement	Ornamental purpose
Commelina communis	Release in nature	Landscape/flora/fauna improvement
Commelina communis	Transport - Contaminant	Seed contaminant
Commelina diffusa	Escape from confinement	Ornamental purpose
Murdannia keisak	Escape from confinement	Ornamental purpose
Murdannia nudiflora	Transport - Contaminant	Transportation of habitat material
Murdannia nudiflora	Transport - Stowaway	Other transport as stowaway
Murdannia nudiflora	Transport - Stowaway	Machinery/equipment
Murdannia nudiflora	Unaided	Unaided
Eichhornia azurea	Escape from confinement	Pet/aquarium/terrarium species
Eichhornia azurea	Escape from confinement	Ornamental purpose
Eichhornia azurea	Escape from confinement	Horticulture
Eichhornia crassipes	Escape from confinement	Ornamental purpose
Eichhornia crassipes	Release in nature	Landscape/flora/fauna improvement
Eichhornia crassipes	Escape from confinement	Botanical garden/zoo/aquaria
Eichhornia crassipes	Escape from confinement	Pet/aquarium/terrarium species
Eichhornia crassipes	Escape from confinement	Horticulture
Eichhornia crassipes	Transport - Stowaway	Machinery/equipment
Eichhornia crassipes	Release in nature	Release in nature for use
Eichhornia crassipes	Transport - Stowaway	Vehicles
Eichhornia crassipes	Release in nature	Other intentional release
Eichhornia diversifolia	Escape from confinement	Pet/aquarium/terrarium species
Eichhornia diversifolia	Release in nature	Other intentional release
Heteranthera limosa	Transport -	Seed contaminant

	Contaminant	
Heteranthera limosa	Release in nature	Other intentional release
Heteranthera limosa	Escape from confinement	Pet/aquarium/terrarium species
Heteranthera limosa	Transport - Stowaway	Vehicles
Heteranthera limosa	Unaided	Unaided
Heteranthera reniformis	Transport - Contaminant	Seed contaminant
Heteranthera reniformis	Release in nature	Other intentional release
Heteranthera reniformis	Escape from confinement	Pet/aquarium/terrarium species
Heteranthera reniformis	Transport - Stowaway	Vehicles
Heteranthera rotundifolia	Transport - Contaminant	Seed contaminant
Heteranthera rotundifolia	Release in nature	Other intentional release
Heteranthera rotundifolia	Transport - Stowaway	Vehicles
Heteranthera zosterifolia	Release in nature	Landscape/flora/fauna improvement
Heteranthera zosterifolia	Unaided	Unaided
Pontederia cordata	Escape from confinement	Ornamental purpose
Pontederia cordata	Release in nature	Release in nature for use
Pontederia cordata	Escape from confinement	Horticulture
Pontederia rotundifolia	Unaided	Unaided
Bolboschoenus glaucus	Release in nature	Other intentional release
Carex crawfordii	Release in nature	Other intentional release
Cyperus aggregatus	Transport - Contaminant	Trade of contaminated commodities
Cyperus alternifolius	Escape from confinement	Horticulture
Cyperus alternifolius	Escape from confinement	Ornamental purpose
Cyperus alternifolius	Escape from confinement	Pet/aquarium/terrarium species
Cyperus amuricus	Release in nature	Other intentional release
Cyperus difformis	Escape from confinement	Agriculture
Cyperus difformis	Transport - Contaminant	Transportation of habitat material
Cyperus difformis	Transport - Stowaway	Other transport as stowaway
Cyperus difformis	Transport - Stowaway	Machinery/equipment
Cyperus difformis	Unaided	Unaided
Cyperus difformis	Transport -	Trade of contaminated commodities

	Contaminant	
Cyperus eragrostis	Escape from confinement	Ornamental purpose
Cyperus eragrostis	Transport - Contaminant	Seed contaminant
Cyperus eragrostis	Release in nature	Other intentional release
Cyperus eragrostis	Transport - Contaminant	Trade of contaminated commodities
Cyperus esculentus	Escape from confinement	Agriculture
Cyperus esculentus	Escape from confinement	Horticulture
Cyperus esculentus	Release in nature	Other intentional release
Cyperus esculentus	Escape from confinement	Cultivation and Livestock
Cyperus esculentus	Escape from confinement	Ornamental purpose
Cyperus haspan	Escape from confinement	Horticulture
Cyperus imbricatus	Escape from confinement	Horticulture
Cyperus imbricatus	Escape from confinement	Ornamental purpose
Cyperus imbricatus	Transport - Contaminant	Transportation of habitat material
Cyperus imbricatus	Transport - Stowaway	Other transport as stowaway
Cyperus imbricatus	Unaided	Unaided
Cyperus imbricatus	Escape from confinement	Cultivation and Livestock
Cyperus imbricatus	Transport - Contaminant	Trade of contaminated commodities
Cyperus involucratus	Escape from confinement	Ornamental purpose
Cyperus involucratus	Unaided	Unaided
Cyperus longus	Escape from confinement	Horticulture
Cyperus meyenianus	Escape from confinement	Horticulture
Cyperus odoratus	Release in nature	Other intentional release
Cyperus papyrus	Escape from confinement	Botanical garden/zoo/aquaria
Cyperus papyrus	Escape from confinement	Ornamental purpose
Cyperus papyrus	Transport - Stowaway	Hitchhiker
Cyperus papyrus	Unaided	Unaided
Cyperus papyrus	Escape from confinement	Horticulture

Cyperus papyrus	Escape from confinement	Cultivation and Livestock
Cyperus reflexus	Transport - Contaminant	Trade of contaminated commodities
Cyperus rotundus	Transport - Contaminant	Transportation of habitat material
Cyperus rotundus	Escape from confinement	Agriculture
Cyperus rotundus	Transport - Contaminant	Food contaminant
Cyperus rotundus	Transport - Contaminant	Seed contaminant
Cyperus rotundus	Transport - Stowaway	Ship/boat ballast water
Cyperus rotundus	Release in nature	Other intentional release
Cyperus squarrosus	Transport - Contaminant	Trade of contaminated commodities
Cyperus virens	Transport - Contaminant	Trade of contaminated commodities
Eleocharis flavescens	Release in nature	Other intentional release
Eleocharis bonariensis	Unaided	Unaided
Eleocharis parvula	Transport - Contaminant	Seed contaminant
Eleocharis parvula	Transport - Contaminant	Trade of contaminated commodities
Fimbristylis cymosa	Escape from confinement	Horticulture
Fimbristylis cymosa	Transport - Contaminant	Transportation of habitat material
Fimbristylis cymosa	Unaided	Unaided
Fimbristylis ferruginea	Unaided	Unaided
Fimbristylis littoralis	Escape from confinement	Agriculture
Fimbristylis littoralis	Transport - Contaminant	Transportation of habitat material
Fimbristylis littoralis	Transport - Stowaway	Other transport as stowaway
Fimbristylis littoralis	Transport - Stowaway	Vehicles
Fimbristylis littoralis	Transport - Stowaway	Machinery/equipment
Fimbristylis littoralis	Unaided	Unaided
Kyllinga brevifolia	Release in nature	Other intentional release
Kyllinga brevifolia	Unaided	Unaided
Pycreus polystachyos	Unaided	Unaided
Juncus anthelatus	Unaided	Unaided
Juncus articulatus	Escape from confinement	Ornamental purpose
Juncus articulatus	Unaided	Unaided

Juncus bufonius	Unaided	Unaided
Juncus effusus	Transport - Contaminant	Transportation of habitat material
Juncus effusus	Transport - Stowaway	Hitchhiker
Juncus effusus	Transport - Stowaway	Vehicles
Juncus effusus	Unaided	Unaided
Juncus effusus	Escape from confinement	Horticulture
Juncus hybridus	Unaided	Unaided
Juncus inflexus	Unaided	Unaided
Juncus ensifolius	Escape from confinement	Pet/aquarium/terrarium species
Juncus ensifolius	Escape from confinement	Ornamental purpose
Juncus ensifolius	Escape from confinement	Horticulture
Juncus ensifolius	Escape from confinement	Agriculture
Juncus ensifolius	Escape from confinement	Research and ex-situ breeding
Juncus ensifolius	Release in nature	Introduction for conservation purposes or wildlife management
Juncus ensifolius	Release in nature	Landscape/flora/fauna improvement
Juncus ensifolius	Release in nature	Release in nature for use
Juncus ensifolius	Transport - Contaminant	Transportation of habitat material
Juncus ensifolius	Transport - Stowaway	Hitchhiker
Juncus ensifolius	Transport - Stowaway	Vehicles
Juncus ensifolius	Transport - Stowaway	Machinery/equipment
Juncus ensifolius	Unaided	Unaided
Juncus ensifolius	Escape from confinement	Cultivation and Livestock
Juncus conglomeratus	Unaided	Unaided
Juncus striatus	Unaided	Unaided
Mayaca fluviatilis	Escape from confinement	Pet/aquarium/terrarium species
Agrostis lachnantha	Transport - Contaminant	Trade of contaminated commodities
Beckmannia syzigachne	Transport - Contaminant	Seed contaminant
Beckmannia syzigachne	Release in nature	Other intentional release
Beckmannia syzigachne	Escape from confinement	Ornamental purpose
Beckmannia syzigachne	Transport -	Trade of contaminated commodities

	Contaminant	
Saccharum ravennae	Escape from confinement	Horticulture
Saccharum ravennae	Escape from confinement	Ornamental purpose
Saccharum ravennae	Escape from confinement	Research and ex-situ breeding
Saccharum ravennae	Release in nature	Landscape/flora/fauna improvement
Saccharum ravennae	Unaided	Unaided
Sacciolepis indica	Transport - Stowaway	Hitchhiker
Spartina pectinata	Escape from confinement	Horticulture
Spartina pectinata	Escape from confinement	Ornamental purpose
Spartina pectinata	Release in nature	Other intentional release
Zizania aquatica	Escape from confinement	Aquaculture
Zizania aquatica	Escape from confinement	Ornamental purpose
Zizania latifolia	Escape from confinement	Aquaculture
Zizania latifolia	Escape from confinement	Ornamental purpose
Zizania latifolia	Release in nature	Landscape/flora/fauna improvement
Zizania latifolia	Escape from confinement	Agriculture
Zizania latifolia	Transport - Stowaway	Ship/boat ballast water
Arundo donax	Escape from confinement	Horticulture
Arundo donax	Escape from confinement	Agriculture
Arundo donax	Escape from confinement	Ornamental purpose
Arundo donax	Release in nature	Landscape/flora/fauna improvement
Arundo donax	Escape from confinement	Other escape from confinement
Arundo donax	Transport - Contaminant	Transportation of habitat material
Arundo donax	Transport - Contaminant	Contaminant on plants
Arundo donax	Transport - Stowaway	Other transport as stowaway
Arundo donax	Transport - Stowaway	Vehicles
Arundo donax	Transport - Stowaway	Machinery/equipment
Arundo donax	Unaided	Unaided

Arundo donax	Escape from confinement	Aquaculture
Arundo donax	Escape from confinement	Cultivation and Livestock
Brachiaria mutica	Transport - Contaminant	Contaminant on animals
Brachiaria mutica	Escape from confinement	Agriculture
Brachiaria mutica	Transport - Contaminant	Transportation of habitat material
Brachiaria mutica	Transport - Stowaway	Other transport as stowaway
Brachiaria mutica	Transport - Stowaway	Vehicles
Brachiaria mutica	Transport - Stowaway	Machinery/equipment
Brachiaria mutica	Unaided	Unaided
Brachiaria mutica	Escape from confinement	Horticulture
Brachiaria mutica	Escape from confinement	Cultivation and Livestock
Brachiaria subquadripara	Corridor	Interconnected waterways/basins/seas
Brachiaria subquadripara	Escape from confinement	Forestry
Brachiaria subquadripara	Escape from confinement	Live food & live bait
Brachiaria subquadripara	Escape from confinement	Horticulture
Brachiaria subquadripara	Escape from confinement	Research and ex-situ breeding
Brachiaria subquadripara	Escape from confinement	Agriculture
Brachiaria subquadripara	Transport - Contaminant	Transportation of habitat material
Brachiaria subquadripara	Transport - Stowaway	Hitchhiker
Brachiaria subquadripara	Transport - Stowaway	People and their luggage/equipment
Brachiaria subquadripara	Transport - Stowaway	Vehicles
Brachiaria subquadripara	Transport - Stowaway	Machinery/equipment
Brachiaria subquadripara	Transport - Stowaway	Container/bulk
Brachiaria subquadripara	Unaided	Unaided
Echinochloa colona	Escape from confinement	Agriculture
Echinochloa crus-galli	Escape from confinement	Agriculture
Echinochloa crus-galli	Transport -	Transportation of habitat material

	Contaminant	
Echinochloa crus-galli	Transport - Stowaway	Other transport as stowaway
Echinochloa crus-galli	Transport - Stowaway	Machinery/equipment
Echinochloa crus-galli	Unaided	Unaided
Echinochloa crus-galli	Transport - Contaminant	Seed contaminant
Echinochloa crus-galli	Transport - Contaminant	Trade of contaminated commodities
Echinochloa oryzoides	Transport - Contaminant	Seed contaminant
Echinochloa oryzoides	Release in nature	Other intentional release
Echinochloa oryzoides	Transport - Contaminant	Trade of contaminated commodities
Echinochloa oryzoides	Transport - Stowaway	Vehicles
Echinochloa pyramidalis	Escape from confinement	Agriculture
Echinochloa pyramidalis	Escape from confinement	Research and ex-situ breeding
Echinochloa pyramidalis	Release in nature	Landscape/flora/fauna improvement
Echinochloa pyramidalis	Transport - Stowaway	Hitchhikers in or on airplane
Echinochloa pyramidalis	Unaided	Unaided
Glyceria declinata	Corridor	Interconnected waterways/basins/seas
Glyceria declinata	Escape from confinement	Horticulture
Glyceria declinata	Transport - Stowaway	Hitchhiker
Glyceria maxima	Corridor	Interconnected waterways/basins/seas
Glyceria maxima	Escape from confinement	Pet/aquarium/terrarium species
Glyceria maxima	Escape from confinement	Ornamental purpose
Glyceria maxima	Escape from confinement	Horticulture
Glyceria maxima	Escape from confinement	Agriculture
Glyceria maxima	Transport - Stowaway	People and their luggage/equipment
Glyceria maxima	Transport - Stowaway	Vehicles
Glyceria maxima	Transport - Stowaway	Machinery/equipment
Glyceria maxima	Unaided	Unaided
Glyceria maxima	Transport - Contaminant	Contaminant on animals
Glyceria striata	Escape from	Ornamental purpose

	confinement	
Glyceria striata	Transport - Contaminant	Seed contaminant
Glyceria striata	Release in nature	Other intentional release
Glyceria striata	Transport - Contaminant	Trade of contaminated commodities
Glyceria striata	Transport - Stowaway	Vehicles
Helictotrichon neesii	Transport - Contaminant	Trade of contaminated commodities
Hymenachne amplexicaulis	Corridor	Interconnected waterways/basins/seas
Hymenachne amplexicaulis	Escape from confinement	Agriculture
Hymenachne amplexicaulis	Transport - Stowaway	Angling/fishing aquaculture equipment
Hymenachne amplexicaulis	Transport - Contaminant	Transportation of habitat material
Hymenachne amplexicaulis	Transport - Stowaway	People and their luggage/equipment
Hymenachne amplexicaulis	Transport - Stowaway	Machinery/equipment
Hymenachne amplexicaulis	Unaided	Unaided
Ischaemum rugosum	Transport - Contaminant	Transportation of habitat material
Ischaemum rugosum	Transport - Stowaway	Other transport as stowaway
Leptochloa fusca	Corridor	Interconnected waterways/basins/seas
Leptochloa fusca	Escape from confinement	Pet/aquarium/terrarium species
Leptochloa fusca	Escape from confinement	Ornamental purpose
Leptochloa fusca	Escape from confinement	Agriculture
Leptochloa fusca	Escape from confinement	Horticulture
Leptochloa fusca	Release in nature	Landscape/flora/fauna improvement
Leptochloa fusca	Transport - Contaminant	Transportation of habitat material
Leptochloa fusca	Transport - Stowaway	Vehicles
Leptochloa fusca	Transport - Stowaway	Machinery/equipment
Leptochloa fusca	Transport - Stowaway	Hitchhikers in or on airplane
Leptochloa fusca	Unaided	Unaided
Leptochloa fusca	Transport - Contaminant	Seed contaminant
Leptochloa fusca	Transport -	Trade of contaminated commodities

	Contaminant	
Oryza rufipogon	Escape from confinement	Cultivation and Livestock
Oryza rufipogon	Transport - Contaminant	Trade of contaminated commodities
Oryza sativa	Escape from confinement	Agriculture
Oryza sativa	Escape from confinement	Horticulture
Oryza sativa	Escape from confinement	Cultivation and Livestock
Oryza sativa	Escape from confinement	Ornamental purpose
Panicum dichotomiflorum	Escape from confinement	Agriculture
Panicum dichotomiflorum	Transport - Contaminant	Seed contaminant
Panicum dichotomiflorum	Release in nature	Other intentional release
Panicum dichotomiflorum	Escape from confinement	Cultivation and Livestock
Panicum dichotomiflorum	Transport - Contaminant	Trade of contaminated commodities
Panicum dichotomiflorum	Transport - Stowaway	Vehicles
Panicum dichotomiflorum	Unaided	Unaided
Panicum maximum	Escape from confinement	Agriculture
Panicum repens	Escape from confinement	Agriculture
Panicum repens	Escape from confinement	Horticulture
Panicum repens	Escape from confinement	Cultivation and Livestock
Paspalidium geminatum	Release in nature	Landscape/flora/fauna improvement
Paspalum distichum	Escape from confinement	Agriculture
Paspalum distichum	Transport - Contaminant	Contaminant on plants
Paspalum distichum	Transport - Contaminant	Seed contaminant
Paspalum distichum	Release in nature	Erosion control/ dune stabilization
Paspalum distichum	Release in nature	Landscape/flora/fauna improvement
Paspalum distichum	Transport - Contaminant	Trade of contaminated commodities
Paspalum scrobiculatum	Transport - Contaminant	Transportation of habitat material
Paspalum vaginatum	Escape from confinement	Agriculture
Paspalum vaginatum	Escape from confinement	Ornamental purpose

Paspalum vaginatum	Escape from confinement	Horticulture
Paspalum vaginatum	Release in nature	Landscape/flora/fauna improvement
Paspalum vaginatum	Transport - Stowaway	Vehicles
Paspalum vaginatum	Transport - Stowaway	Machinery/equipment
Paspalum vaginatum	Unaided	Unaided
Phalaris arundinacea	Escape from confinement	Horticulture
Phalaris arundinacea	Release in nature	Landscape/flora/fauna improvement
Phalaris arundinacea	Escape from confinement	Ornamental purpose
Phalaris arundinacea	Escape from confinement	Agriculture
Phragmites australis	Corridor	Interconnected waterways/basins/seas
Phragmites australis	Escape from confinement	Ornamental purpose
Phragmites australis	Escape from confinement	Research and ex-situ breeding
Phragmites australis	Escape from confinement	Other escape from confinement
Phragmites australis	Transport - Stowaway	Hitchhikers in or on airplane
Phragmites australis	Unaided	Unaided
Phragmites australis	Escape from confinement	Horticulture
Phragmites australis	Release in nature	Erosion control/ dune stabilization
Phragmites australis	Release in nature	Landscape/flora/fauna improvement
Setaria parviflora	Escape from confinement	Horticulture
Setaria parviflora	Transport - Contaminant	Contaminant on plants
Setaria parviflora	Transport - Stowaway	Hitchhiker
Setaria parviflora	Unaided	Unaided
Typha angustifolia	Unaided	Unaided
Typha angustifolia	Escape from confinement	Ornamental purpose
Typha domingensis	Transport - Contaminant	Contaminant on animals
Typha domingensis	Corridor	Interconnected waterways/basins/seas
Typha domingensis	Escape from confinement	Agriculture
Typha domingensis	Transport - Stowaway	Hitchhiker
Typha domingensis	Transport - Stowaway	People and their luggage/equipment
Typha domingensis	Unaided	Unaided

Typha latifolia	Corridor	Interconnected waterways/basins/seas
Typha latifolia	Escape from confinement	Horticulture
Typha latifolia	Escape from confinement	Aquaculture
Typha latifolia	Escape from confinement	Ornamental purpose
Typha latifolia	Escape from confinement	Other escape from confinement
Typha latifolia	Transport - Contaminant	Transportation of habitat material
Typha latifolia	Unaided	Unaided
Typha latifolia	Transport - Stowaway	Machinery/equipment
Typha latifolia	Transport - Stowaway	People and their luggage/equipment
Typha laxmannii	Escape from confinement	Ornamental purpose
Typha laxmannii	Release in nature	Landscape/flora/fauna improvement
Typha laxmannii	Escape from confinement	Horticulture
Typha laxmannii	Release in nature	Other intentional release
Typha minima	Escape from confinement	Horticulture
Typha minima	Escape from confinement	Cultivation and Livestock
Thalia dealbata	Escape from confinement	Horticulture
Hedychium coronarium	Escape from confinement	Pet/aquarium/terrarium species
Hedychium coronarium	Escape from confinement	Ornamental purpose
Hedychium coronarium	Escape from confinement	Horticulture
Hedychium coronarium	Escape from confinement	Botanical garden/zoo/aquaria
Hedychium coronarium	Escape from confinement	Research and ex-situ breeding
Hedychium coronarium	Release in nature	Release in nature for use
Hedychium coronarium	Transport - Contaminant	Contaminant on plants
Hedychium coronarium	Transport - Stowaway	Machinery/equipment
Hedychium coronarium	Unaided	Unaided
Apium graveolens	Escape from confinement	Agriculture
Apium graveolens	Escape from confinement	Horticulture
Apium graveolens	Release in nature	Landscape/flora/fauna improvement

Apium graveolens	Release in nature	Other intentional release
Apium graveolens	Escape from confinement	Cultivation and Livestock
Apium graveolens	Escape from confinement	Ornamental purpose
Apium graveolens	Unaided	Unaided
Centella asiatica	Escape from confinement	Ornamental purpose
Centella asiatica	Release in nature	Release in nature for use
Centella asiatica	Transport - Contaminant	Contaminant on plants
Centella asiatica	Transport - Stowaway	Machinery/equipment
Eryngium pandanifolium	Escape from confinement	Ornamental purpose
Lilaeopsis carolinensis	Unaided	Unaided
Oenanthe javanica	Escape from confinement	Horticulture
Sium sisarum	Release in nature	Other intentional release
Hydrocotyle bonariensis	Unaided	Unaided
Hydrocotyle ranunculoides	Escape from confinement	Pet/aquarium/terrarium species
Hydrocotyle ranunculoides	Escape from confinement	Ornamental purpose
Hydrocotyle ranunculoides	Transport - Contaminant	Contaminant on plants
Hydrocotyle ranunculoides	Unaided	Unaided
Hydrocotyle ranunculoides	Release in nature	Other intentional release
Hydrocotyle umbellata	Escape from confinement	Horticulture
Hydrocotyle sibthorpioides	Escape from confinement	Ornamental purpose
Hydrocotyle sibthorpioides	Escape from confinement	Pet/aquarium/terrarium species
Hydrocotyle verticillata	Unaided	Unaided
Centipeda minima	Transport - Contaminant	Trade of contaminated commodities
Eclipta prostrata	Escape from confinement	Ornamental purpose
Eclipta prostrata	Transport - Contaminant	Seed contaminant
Eclipta prostrata	Transport - Stowaway	Vehicles
Shinnersia rivularis	Unaided	Unaided
Acmella uliginosa	Transport - Contaminant	Transportation of habitat material
Acmella uliginosa	Transport -	Other transport as stowaway

	Stowaway	
Acmella uliginosa	Transport - Stowaway	Machinery/equipment
Acmella uliginosa	Unaided	Unaided
Bidens frondosa	Transport - Contaminant	Contaminant on animals
Bidens frondosa	Escape from confinement	Ornamental purpose
Bidens frondosa	Release in nature	Release in nature for use
Bidens frondosa	Transport - Contaminant	Transportation of habitat material
Bidens frondosa	Transport - Stowaway	Hitchhiker
Bidens frondosa	Unaided	Unaided
Bidens frondosa	Release in nature	Landscape/flora/fauna improvement
Bidens frondosa	Transport - Contaminant	Seed contaminant
Bidens frondosa	Release in nature	Other intentional release
Bidens frondosa	Transport - Contaminant	Trade of contaminated commodities
Bidens tripartita	Escape from confinement	Horticulture
Cotula coronopifolia	Escape from confinement	Horticulture
Cotula coronopifolia	Escape from confinement	Ornamental purpose
Cotula coronopifolia	Transport - Contaminant	Trade of contaminated commodities
Gymnocoronis spilanthoides	Escape from confinement	Horticulture
Gymnocoronis spilanthoides	Escape from confinement	Ornamental purpose
Gymnocoronis spilanthoides	Escape from confinement	Pet/aquarium/terrarium species
Gymnocoronis spilanthoides	Transport - Stowaway	Machinery/equipment
Gymnocoronis spilanthoides	Unaided	Unaided
Gymnocoronis spilanthoides	Release in nature	Other intentional release
Menyanthes trifoliata	Escape from confinement	Horticulture
Nymphoides aquatica	Escape from confinement	Pet/aquarium/terrarium species
Nymphoides aquatica	Escape from confinement	Horticulture
Nymphoides cristata	Escape from confinement	Horticulture
Nymphoides indica	Escape from confinement	Horticulture

Nymphoides peltata	Corridor	Interconnected waterways/basins/seas
Nymphoides peltata	Escape from confinement	Pet/aquarium/terrarium species
Nymphoides peltata	Escape from confinement	Ornamental purpose
Nymphoides peltata	Escape from confinement	Horticulture
Nymphoides peltata	Escape from confinement	Aquaculture
Nymphoides peltata	Release in nature	Fishery in the wild
Nymphoides peltata	Release in nature	Other intentional release
Nymphoides peltata	Transport - Stowaway	Hitchhikers on ship/boat
Nymphoides peltata	Unaided	Unaided
Nymphoides peltata	Escape from confinement	Cultivation and Livestock
Myosotis scorpioides	Escape from confinement	Agriculture
Myosotis scorpioides	Escape from confinement	Ornamental purpose
Myosotis scorpioides	Escape from confinement	Horticulture
Nasturtium officinale	Escape from confinement	Horticulture
Nasturtium officinale	Escape from confinement	Ornamental purpose
Nasturtium officinale	Escape from confinement	Cultivation and Livestock
Nasturtium microphyllum	Escape from confinement	Aquaculture
Nasturtium microphyllum	Escape from confinement	Agriculture
Nasturtium microphyllum	Transport - Stowaway	Hitchhiker
Nasturtium microphyllum	Transport - Stowaway	Vehicles
Nasturtium microphyllum	Transport - Stowaway	Machinery/equipment
Nasturtium microphyllum	Unaided	Unaided
Rorippa curvisiliqua	Unaided	Unaided
Rorippa palustris	Unaided	Unaided
Alternanthera ficoidea	Transport - Contaminant	Seed contaminant
Alternanthera ficoidea	Transport - Contaminant	Trade of contaminated commodities
Alternanthera philoxeroides	Escape from confinement	Ornamental purpose
Alternanthera philoxeroides	Transport - Contaminant	Transportation of habitat material

Alternanthera philoxeroides	Transport - Stowaway	People and their luggage/equipment
Alternanthera philoxeroides	Transport - Stowaway	Vehicles
Alternanthera philoxeroides	Transport - Stowaway	Ship/boat ballast water
Alternanthera philoxeroides	Unaided	Unaided
Alternanthera philoxeroides	Transport - Contaminant	Trade of contaminated commodities
Alternanthera sessilis	Escape from confinement	Agriculture
Alternanthera sessilis	Escape from confinement	Ornamental purpose
Alternanthera sessilis	Transport - Stowaway	Other transport as stowaway
Alternanthera sessilis	Unaided	Unaided
Alternanthera sessilis	Escape from confinement	Pet/aquarium/terrarium species
Alternanthera sessilis	Escape from confinement	Horticulture
Alternanthera sessilis	Transport - Contaminant	Trade of contaminated commodities
Persicaria lapathifolia	Escape from confinement	Agriculture
Persicaria lapathifolia	Transport - Contaminant	Seed contaminant
Persicaria maculosa	Escape from confinement	Ornamental purpose
Persicaria maculosa	Transport - Contaminant	Transportation of habitat material
Persicaria senegalensis	Escape from confinement	Cultivation and Livestock
Montia parvifolia	Escape from confinement	Ornamental purpose
Ceratophyllum demersum	Escape from confinement	Pet/aquarium/terrarium species
Ceratophyllum demersum	Escape from confinement	Ornamental purpose
Ceratophyllum demersum	Escape from confinement	Aquaculture
Ceratophyllum demersum	Release in nature	Fishery in the wild
Ceratophyllum demersum	Transport - Stowaway	Hitchhiker
Ceratophyllum demersum	Transport - Stowaway	Vehicles
Ceratophyllum demersum	Unaided	Unaided
Ceratophyllum demersum	Escape from confinement	Horticulture
Ceratophyllum demersum	Transport -	Angling/fishing aquaculture equipment

	Stowaway	
Ceratophyllum submersum	Unaided	Unaided
Lysimachia ciliata	Escape from confinement	Horticulture
Lysimachia ciliata	Escape from confinement	Cultivation and Livestock
Lysimachia ciliata	Escape from confinement	Ornamental purpose
Hottonia palustris	Escape from confinement	Ornamental purpose
Hottonia palustris	Release in nature	Other intentional release
Aeschynomene americana	Escape from confinement	Agriculture
Aeschynomene americana	Release in nature	Landscape/flora/fauna improvement
Aeschynomene americana	Transport - Contaminant	Transportation of habitat material
Aeschynomene americana	Transport - Contaminant	Contaminant on plants
Aeschynomene americana	Transport - Stowaway	Other transport as stowaway
Aeschynomene americana	Transport - Stowaway	Vehicles
Aeschynomene americana	Unaided	Unaided
Aeschynomene americana	Transport - Contaminant	Seed contaminant
Aeschynomene indica	Transport - Contaminant	Seed contaminant
Aeschynomene indica	Transport - Contaminant	Trade of contaminated commodities
Galium palustre	Unaided	Unaided
Oldenlandia capensis	Unaided	Unaided
Hygrophila difformis	Escape from confinement	Horticulture
Hygrophila difformis	Escape from confinement	Pet/aquarium/terrarium species
Hygrophila corymbosa	Escape from confinement	Pet/aquarium/terrarium species
Hygrophila corymbosa	Release in nature	Other intentional release
Hygrophila polysperma	Corridor	Interconnected waterways/basins/seas
Hygrophila polysperma	Escape from confinement	Pet/aquarium/terrarium species
Hygrophila polysperma	Escape from confinement	Ornamental purpose
Hygrophila polysperma	Escape from confinement	Horticulture
Hygrophila polysperma	Transport - Stowaway	Hitchhiker
Hygrophila polysperma	Transport -	Hitchhikers on ship/boat

	Stowaway	
Hygrophila polysperma	Unaided	Unaided
Mentha aquatica	Escape from confinement	Ornamental purpose
Mentha arvensis	Release in nature	Other intentional release
Mentha longifolia	Escape from confinement	Agriculture
Mentha longifolia	Escape from confinement	Horticulture
Mentha pulegium	Escape from confinement	Pet/aquarium/terrarium species
Mentha pulegium	Escape from confinement	Ornamental purpose
Mentha pulegium	Escape from confinement	Agriculture
Mentha spicata	Escape from confinement	Horticulture
Mentha spicata	Escape from confinement	Agriculture
Mentha spicata	Escape from confinement	Ornamental purpose
Mentha spicata	Release in nature	Landscape/flora/fauna improvement
Utricularia gibba	Transport - Contaminant	Contaminant on animals
Utricularia gibba	Escape from confinement	Pet/aquarium/terrarium species
Utricularia gibba	Release in nature	Fishery in the wild
Utricularia gibba	Transport - Stowaway	Machinery/equipment
Utricularia gibba	Unaided	Unaided
Utricularia gibba	Escape from confinement	Botanical garden/zoo/aquaria
Utricularia gibba	Corridor	Interconnected waterways/basins/seas
Mimulus luteus	Escape from confinement	Ornamental purpose
Mimulus guttatus	Escape from confinement	Ornamental purpose
Mimulus guttatus	Release in nature	Landscape/flora/fauna improvement
Bacopa caroliniana	Escape from confinement	Pet/aquarium/terrarium species
Bacopa caroliniana	Escape from confinement	Horticulture
Bacopa caroliniana	Release in nature	Other intentional release
Bacopa monnieri	Escape from confinement	Ornamental purpose
Bacopa monnieri	Escape from confinement	Pet/aquarium/terrarium species
Bacopa monnieri	Release in nature	Release in nature for use
Bacopa monnieri	Transport -	Other transport as stowaway

	Stowaway	
Bacopa monnieri	Unaided	Unaided
Bacopa rotundifolia	Transport - Contaminant	Seed contaminant
Bacopa rotundifolia	Transport - Contaminant	Trade of contaminated commodities
Limnophila sessiliflora	Escape from confinement	Pet/aquarium/terrarium species
Limnophila sessiliflora	Release in nature	Other intentional release
Lindernia crustacea	Transport - Contaminant	Transportation of habitat material
Lindernia crustacea	Transport - Stowaway	Other transport as stowaway
Lindernia crustacea	Unaided	Unaided
Lindernia dubia	Transport - Contaminant	Seed contaminant
Lindernia dubia	Transport - Contaminant	Trade of contaminated commodities
Bergia capensis	Escape from confinement	Horticulture
Bergia capensis	Transport - Contaminant	Seed contaminant
Bergia capensis	Transport - Contaminant	Trade of contaminated commodities
Elatine ambigua	Release in nature	Other intentional release
Elatine ambigua	Escape from confinement	Cultivation and Livestock
Ammannia auriculata	Transport - Contaminant	Trade of contaminated commodities
Ammannia auriculata	Transport - Stowaway	Vehicles
Ammannia baccifera	Transport - Contaminant	Trade of contaminated commodities
Ammannia coccinea	Transport - Contaminant	Seed contaminant
Ammannia coccinea	Transport - Contaminant	Trade of contaminated commodities
Ammannia coccinea	Transport - Stowaway	Vehicles
Ammannia robusta	Unaided	Unaided
Cuphea carthagenensis	Corridor	Interconnected waterways/basins/seas
Cuphea carthagenensis	Escape from confinement	Agriculture
Cuphea carthagenensis	Release in nature	Release in nature for use
Cuphea carthagenensis	Transport - Contaminant	Transportation of habitat material
Cuphea carthagenensis	Transport - Stowaway	Hitchhiker
Cuphea carthagenensis	Transport -	Vehicles

	Stowaway	
Cuphea carthagenensis	Transport - Stowaway	Machinery/equipment
Cuphea carthagenensis	Unaided	Unaided
Lythrum salicaria	Escape from confinement	Pet/aquarium/terrarium species
Lythrum salicaria	Escape from confinement	Ornamental purpose
Lythrum salicaria	Escape from confinement	Horticulture
Lythrum salicaria	Escape from confinement	Botanical garden/zoo/aquaria
Lythrum salicaria	Escape from confinement	Live food & live bait
Lythrum salicaria	Release in nature	Release in nature for use
Lythrum salicaria	Transport - Contaminant	Transportation of habitat material
Lythrum salicaria	Transport - Contaminant	Contaminant on plants
Lythrum salicaria	Transport - Stowaway	People and their luggage/equipment
Lythrum salicaria	Transport - Stowaway	Vehicles
Lythrum salicaria	Transport - Stowaway	Machinery/equipment
Lythrum salicaria	Transport - Stowaway	Ship/boat ballast water
Lythrum salicaria	Unaided	Unaided
Lythrum salicaria	Release in nature	Landscape/flora/fauna improvement
Rotala densiflora	Transport - Stowaway	Vehicles
Rotala filiformis	Transport - Contaminant	Trade of contaminated commodities
Rotala filiformis	Transport - Stowaway	Vehicles
Rotala indica	Escape from confinement	Pet/aquarium/terrarium species
Rotala indica	Escape from confinement	Horticulture
Rotala indica	Transport - Contaminant	Trade of contaminated commodities
Rotala indica	Transport - Stowaway	Vehicles
Rotala ramosior	Transport - Contaminant	Seed contaminant
Rotala ramosior	Transport - Contaminant	Trade of contaminated commodities
Rotala ramosior	Transport - Stowaway	Vehicles
Rotala rotundifolia	Release in nature	Other intentional release

Trapa natans	Corridor	Interconnected waterways/basins/seas
Trapa natans	Escape from confinement	Pet/aquarium/terrarium species
Trapa natans	Escape from confinement	Ornamental purpose
Trapa natans	Escape from confinement	Aquaculture
Trapa natans	Escape from confinement	Botanical garden/zoo/aquaria
Trapa natans	Escape from confinement	Horticulture
Trapa natans	Release in nature	Other intentional release
Trapa natans	Transport - Stowaway	Hitchhiker
Trapa natans	Transport - Stowaway	Machinery/equipment
Trapa natans	Transport - Stowaway	Hitchhikers on ship/boat
Trapa natans	Unaided	Unaided
Trapa natans	Escape from confinement	Cultivation and Livestock
Epilobium ciliatum	Transport - Contaminant	Contaminant on plants
Epilobium ciliatum	Transport - Stowaway	Hitchhiker
Epilobium ciliatum	Unaided	Unaided
Epilobium ciliatum	Escape from confinement	Ornamental purpose
Epilobium ciliatum	Transport - Contaminant	Transportation of habitat material
Epilobium ciliatum	Transport - Contaminant	Seed contaminant
Epilobium hirsutum	Escape from confinement	Cultivation and Livestock
Ludwigia grandiflora	Corridor	Interconnected waterways/basins/seas
Ludwigia grandiflora	Escape from confinement	Pet/aquarium/terrarium species
Ludwigia grandiflora	Escape from confinement	Ornamental purpose
Ludwigia grandiflora	Escape from confinement	Horticulture
Ludwigia grandiflora	Escape from confinement	Aquaculture
Ludwigia grandiflora	Escape from confinement	Botanical garden/zoo/aquaria
Ludwigia grandiflora	Release in nature	Other intentional release
Ludwigia grandiflora	Release in nature	Landscape/flora/fauna improvement
Ludwigia grandiflora	Transport - Contaminant	Contaminant on plants

Ludwigia grandiflora	Transport - Stowaway	Hitchhiker
Ludwigia grandiflora	Transport - Stowaway	People and their luggage/equipment
Ludwigia grandiflora	Transport - Stowaway	Machinery/equipment
Ludwigia grandiflora	Unaided	Unaided
Ludwigia hyssopifolia	Escape from confinement	Horticulture
Ludwigia hyssopifolia	Transport - Contaminant	Transportation of habitat material
Ludwigia palustris	Escape from confinement	Pet/aquarium/terrarium species
Ludwigia peploides	Corridor	Interconnected waterways/basins/seas
Ludwigia peploides	Escape from confinement	Pet/aquarium/terrarium species
Ludwigia peploides	Escape from confinement	Ornamental purpose
Ludwigia peploides	Escape from confinement	Horticulture
Ludwigia peploides	Escape from confinement	Aquaculture
Ludwigia peploides	Escape from confinement	Botanical garden/zoo/aquaria
Ludwigia peploides	Release in nature	Other intentional release
Ludwigia peploides	Transport - Contaminant	Contaminant on plants
Ludwigia peploides	Transport - Stowaway	Hitchhiker
Ludwigia peploides	Transport - Stowaway	People and their luggage/equipment
Ludwigia peploides	Transport - Stowaway	Machinery/equipment
Ludwigia peploides	Unaided	Unaided
Ludwigia peploides	Escape from confinement	Cultivation and Livestock
Ludwigia peruviana	Transport - Contaminant	Seed contaminant
Ludwigia repens	Escape from confinement	Ornamental purpose
Ludwigia repens	Release in nature	Landscape/flora/fauna improvement
Ludwigia repens	Escape from confinement	Pet/aquarium/terrarium species
Ludwigia repens	Escape from confinement	Horticulture
Ludwigia repens	Escape from confinement	Cultivation and Livestock
Cabomba caroliniana	Corridor	Interconnected waterways/basins/seas
Cabomba caroliniana	Escape from confinement	Aquaculture

Cabomba caroliniana	Escape from confinement	Pet/aquarium/terrarium species
Cabomba caroliniana	Escape from confinement	Research and ex-situ breeding
Cabomba caroliniana	Release in nature	Other intentional release
Cabomba caroliniana	Transport - Stowaway	Hitchhiker
Cabomba caroliniana	Transport - Stowaway	Machinery/equipment
Cabomba caroliniana	Transport - Stowaway	Hitchhikers in or on airplane
Cabomba caroliniana	Transport - Stowaway	Hitchhikers on ship/boat
Cabomba caroliniana	Unaided	Unaided
Cabomba caroliniana	Escape from confinement	Ornamental purpose
Cabomba caroliniana	Escape from confinement	Horticulture
Cabomba caroliniana	Escape from confinement	Botanical garden/zoo/aquaria
Cabomba caroliniana	Transport - Contaminant	Contaminated bait
Cabomba caroliniana	Transport - Stowaway	Ship/boat hull fouling
Cabomba caroliniana	Transport - Contaminant	Transportation of habitat material
Cabomba haynesii	Escape from confinement	Pet/aquarium/terrarium species
Nuphar advena	Escape from confinement	Cultivation and Livestock
Nuphar advena	Escape from confinement	Ornamental purpose
Nuphar japonica	Escape from confinement	Ornamental purpose
Nuphar japonica	Release in nature	Other intentional release
Nuphar japonica	Escape from confinement	Cultivation and Livestock
Nuphar lutea	Escape from confinement	Horticulture
Nuphar pumila	Escape from confinement	Ornamental purpose
Nuphar pumila	Release in nature	Other intentional release
Nymphaea alba	Escape from confinement	Ornamental purpose
Nymphaea lotus	Corridor	Interconnected waterways/basins/seas
Nymphaea lotus	Escape from confinement	Ornamental purpose
Nymphaea lotus	Release in nature	Release in nature for use
Nymphaea lotus	Transport - Contaminant	Contaminant on plants

Nymphaea lotus	Unaided	Unaided
Nymphaea mexicana	Escape from confinement	Ornamental purpose
Nymphaea mexicana	Escape from confinement	Pet/aquarium/terrarium species
Nymphaea nouchali	Escape from confinement	Pet/aquarium/terrarium species
Nymphaea odorata	Escape from confinement	Horticulture
Nymphaea rubra	Unaided	Unaided
Houttuynia cordata	Escape from confinement	Ornamental purpose
Houttuynia cordata	Escape from confinement	Horticulture
Saururus cernuus	Escape from confinement	Ornamental purpose
Saururus cernuus	Escape from confinement	Horticulture
Nelumbo nucifera	Escape from confinement	Ornamental purpose
Nelumbo nucifera	Release in nature	Landscape/flora/fauna improvement
Nelumbo nucifera	Release in nature	Other intentional release
Nelumbo nucifera	Unaided	Unaided
Myosurus minimus	Transport - Contaminant	Seed contaminant
Myosurus minimus	Transport - Contaminant	Trade of contaminated commodities
Ranunculus lingua	Escape from confinement	Ornamental purpose
Myriophyllum aquaticum	Corridor	Interconnected waterways/basins/seas
Myriophyllum aquaticum	Escape from confinement	Aquaculture
Myriophyllum aquaticum	Escape from confinement	Horticulture
Myriophyllum aquaticum	Escape from confinement	Ornamental purpose
Myriophyllum aquaticum	Escape from confinement	Pet/aquarium/terrarium species
Myriophyllum aquaticum	Release in nature	Other intentional release
Myriophyllum aquaticum	Transport - Contaminant	Contaminant on plants
Myriophyllum aquaticum	Unaided	Unaided
Myriophyllum aquaticum	Release in nature	Landscape/flora/fauna improvement
Myriophyllum aquaticum	Release in nature	Release in nature for use
Myriophyllum aquaticum	Escape from confinement	Botanical garden/zoo/aquaria
Myriophyllum heterophyllum	Escape from confinement	Pet/aquarium/terrarium species
Myriophyllum	Escape from	Ornamental purpose

heterophyllum	confinement	
Myriophyllum heterophyllum	Transport - Stowaway	Hitchhikers on ship/boat
Myriophyllum heterophyllum	Transport - Stowaway	Ship/boat hull fouling
Myriophyllum heterophyllum	Unaided	Unaided
Myriophyllum heterophyllum	Escape from confinement	Horticulture
Myriophyllum heterophyllum	Release in nature	Landscape/flora/fauna improvement
Myriophyllum heterophyllum	Escape from confinement	Cultivation and Livestock
Myriophyllum hippuroides	Escape from confinement	Pet/aquarium/terrarium species
Myriophyllum simulans	Escape from confinement	Pet/aquarium/terrarium species
Myriophyllum spicatum	Corridor	Interconnected waterways/basins/seas
Myriophyllum spicatum	Escape from confinement	Pet/aquarium/terrarium species
Myriophyllum spicatum	Escape from confinement	Ornamental purpose
Myriophyllum spicatum	Escape from confinement	Horticulture
Myriophyllum spicatum	Escape from confinement	Aquaculture
Myriophyllum spicatum	Release in nature	Fishery in the wild
Myriophyllum spicatum	Transport - Stowaway	Angling/fishing aquaculture equipment
Myriophyllum spicatum	Transport - Stowaway	Ship/boat hull fouling
Myriophyllum spicatum	Unaided	Unaided
Myriophyllum spicatum	Escape from confinement	Botanical garden/zoo/aquaria
Myriophyllum spicatum	Transport - Contaminant	Transportation of habitat material
Myriophyllum spicatum	Transport - Stowaway	Hitchhikers on ship/boat
Crassula aquatica	Release in nature	Other intentional release
Crassula aquatica	Escape from confinement	Ornamental purpose
Crassula helmsii	Corridor	Interconnected waterways/basins/seas
Crassula helmsii	Escape from confinement	Pet/aquarium/terrarium species
Crassula helmsii	Escape from confinement	Ornamental purpose
Crassula helmsii	Escape from confinement	Horticulture
Crassula helmsii	Transport - Stowaway	Hitchhiker

Crassula helmsii	Transport - Stowaway	People and their luggage/equipment
Crassula helmsii	Transport - Stowaway	Hitchhikers on ship/boat
Crassula helmsii	Unaided	Unaided
Crassula helmsii	Transport - Contaminant	Transportation of habitat material
Crassula helmsii	Transport - Stowaway	Ship/boat ballast water
Crassula helmsii	Transport - Stowaway	Ship/boat hull fouling
Crassula peduncularis	Escape from confinement	Ornamental purpose
Crassula peduncularis	Transport - Contaminant	Trade of contaminated commodities
Ipomoea aquatica	Escape from confinement	Agriculture
Hypericum mutilum	Escape from confinement	Pet/aquarium/terrarium species
Hypericum mutilum	Escape from confinement	Botanical garden/zoo/aquaria
Corrigiola litoralis	Escape from confinement	Ornamental purpose
Nymphaea marliacea	Unaided	Unaided
Halophila stipulacea	Corridor	Interconnected waterways/basins/seas
Halophila stipulacea	Release in nature	Fishery in the wild
Halophila stipulacea	Transport - Stowaway	Ship/boat ballast water
Halophila stipulacea	Unaided	Unaided
Halophila stipulacea	Transport - Stowaway	Other transport as stowaway
Halophila stipulacea	Transport - Stowaway	Ship/boat hull fouling
Halophila stipulacea	Transport - Stowaway	Hitchhikers on ship/boat
Halophila stipulacea	Escape from confinement	Aquaculture
Artemisia codonocephala	Transport - Contaminant	Seed contaminant
Artemisia codonocephala	Transport - Contaminant	Trade of contaminated commodities
Nymphaea odorata subsp. tuberosa	Escape from confinement	Horticulture
Nymphaea lotus var. thermalis	Release in nature	Landscape/flora/fauna improvement
Nymphaea lotus var. thermalis	Release in nature	Other intentional release
Austroderia richardii	Escape from confinement	Ornamental purpose

APPENDIX C – – Life-form

Note: Readers can request to the corresponding author the full data set and all scripts regarding data manipulation and analysis.

Table C1 – Life-forms based on Schneider et al. 2018. Species names are standardized according to The Plant List (http://www.theplantlist.org/),

standardized_name	Life-form	standardized_name	Life-form
Equisetum hyemale	Emergent	Paspalum intermedium	Emergent
Equisetum palustre	Emergent	Pennisetum macrourum	Emergent
Isoetes tuckermanii	Rooted submerged	Phalaris arundinacea	Emergent
Marsilea minuta	Rooted floating-steamed	Phragmites australis	Emergent
Marsilea crenata	Emergent	Setaria parviflora	Emergent
Marsilea drummondii	Emergent	Sparganium emersum	Emergent
Marsilea hirsuta	Emergent	Sparganium erectum	Emergent
Marsilea macropoda	Emergent	Sparganium eurycarpum	Emergent
Marsilea mutica	Rooted floating-leaved	Sparganium glomeratum	Emergent
Marsilea oligospora	Rooted floating-leaved	Sparganium stoloniferum	Emergent
Marsilea quadrifolia	Rooted floating-steamed	Typha angustifolia	Emergent
Marsilea vestita	Rooted floating-leaved	Typha domingensis	Emergent
Marsilea vestita	Rooted submerged	Typha latifolia	Emergent
Marsilea vestita	Emergent	Typha laxmannii	Emergent
Azolla caroliniana	Free-floating	Typha minima	Emergent
Azolla cristata	Free-floating	Typha orientalis	Emergent
Azolla filiculoides	Free-floating	Xyris indica	Emergent
Azolla japonica	Free-floating	Xyris jupicai	Emergent
Azolla mexicana	Free-floating	Canna glauca	Emergent
Azolla microphylla	Free-floating	Thalia dealbata	Emergent
Azolla pinnata	Free-floating	Thalia geniculata	Emergent
Salvinia adnata	Free-floating	Hedychium coronarium	Emergent
Salvinia auriculata	Free-floating	Apium graveolens	Emergent
Salvinia cucullata	Free-floating	Apium nodiflorum	Rooted submerged
Salvinia minima	Free-floating	Apium repens	Emergent

Salvinia natans	Free-floating	Berula erecta	Emergent
Ceratopteris pteridoides	Free-floating	Centella asiatica	Emergent
Ceratopteris richardii	Rooted floating-steamed	Cicuta bulbifera	Emergent
Ceratopteris richardii	Rooted submerged	Cicuta maculata	Emergent
Ceratopteris richardii	Emergent	Eryngium aquaticum	Emergent
Ceratopteris thalictroides	Emergent	Eryngium foetidum	Emergent
Acorus calamus	Emergent	Eryngium pandanifolium	Emergent
Acorus gramineus	Emergent	Lilaeopsis carolinensis	Emergent
Alisma gramineum	Emergent	Oenanthe aquatica	Emergent
Alisma gramineum	Rooted submerged	Oenanthe fistulosa	Emergent
Alisma lanceolatum	Emergent	Oenanthe javanica	Emergent
Alisma plantago-aquatica	Emergent	Oenanthe javanica	Rooted floating-steamed
Baldellia ranunculoides	Emergent	Oenanthe sarmentosa	Emergent
Caldesia parnassifolia	Rooted floating-leaved	Oxypolis occidentalis	Emergent
Echinodorus berteroi	Emergent	Peucedanum palustre	Emergent
Echinodorus cordifolius	Emergent	Sium latifolium	Emergent
Echinodorus floribundus	Emergent	Sium suave	Emergent
Echinodorus scaber	Emergent	Sium sisarum	Emergent
Helanthium bolivianum	Emergent	Hydrocotyle bonariensis	Emergent
Helanthium bolivianum	Rooted submerged	Hydrocotyle ranunculoides	Rooted floating-steamed
Limnocharis flava	Emergent	Hydrocotyle tripartita	Emergent
Sagittaria brevirostra	Emergent	Hydrocotyle umbellata	Emergent
Sagittaria graminea	Emergent	Hydrocotyle vulgaris	Emergent
Sagittaria guayanensis	Rooted floating-leaved	Hydrocotyle sibthorpioides	Emergent
Sagittaria kurziana	Rooted submerged	Hydrocotyle verticillata	Emergent
Sagittaria latifolia	Emergent	Centipeda minima	Emergent
Sagittaria macrophylla	Emergent	Eclipta prostrata	Emergent
Sagittaria montevidensis	Emergent	Grangea maderaspatana	Emergent

Sagittaria platyphylla	Emergent	Petasites frigidus	Emergent
Sagittaria rigida	Emergent	Shinnersia rivularis	Rooted submerged
Sagittaria sagittifolia	Emergent	Sphaeranthus africanus	Emergent
Sagittaria subulata	Rooted submerged	Sphaeranthus senegalensis	Emergent
Sagittaria trifolia	Emergent	Acmella paniculata	Emergent
Aponogeton distachyos	Rooted floating-leaved	Acmella ciliata	Emergent
Aponogeton madagascariensis	Rooted submerged	Acmella uliginosa	Emergent
Caladium bicolor	Emergent	Bidens cernua	Emergent
Calla palustris	Emergent	Bidens frondosa	Emergent
Cryptocoryne beckettii	Rooted submerged	Bidens parviflora	Emergent
Cryptocoryne beckettii	Emergent	Bidens radiata	Emergent
Cryptocoryne walkeri	Rooted submerged	Bidens tripartita	Emergent
Cryptocoryne wendtii	Rooted submerged	Bidens beckii	Rooted submerged
Cryptocoryne wendtii	Emergent	Bidens laevis	Free-floating
Cyrtosperma merkusii	Emergent	Cotula coronopifolia	Emergent
Lemna aequinoctialis	Free-floating	Enydra fluctuans	Emergent
Lemna disperma	Free-floating	Enydra sessilis	Emergent
Lemna gibba	Free-floating	Gymnocoronis spilanthoides	Emergent
Lemna minor	Free-floating	Jaegeria hirta	Emergent
Lemna minuta	Free-floating	Grammatotheca bergiana	Emergent
Lemna obscura	Free-floating	Isotoma fluviatilis	Emergent
Lemna perpusilla	Free-floating	Lobelia cardinalis	Emergent
Lemna turionifera	Free-floating	Lobelia chinensis	Emergent
Lemna valdiviana	Free-floating	Menyanthes trifoliata	Emergent
Lysichiton camtschatcensis	Emergent	Nymphoides aquatica	Rooted floating-leaved
Orontium aquaticum	Emergent	Nymphoides cristata	Rooted floating-leaved
Peltandra virginica	Emergent	Nymphoides geminata	Rooted floating-leaved
Philodendron bipinnatifidum	Emergent	Nymphoides indica	Rooted floating-leaved
Pistia stratiotes	Free-floating	Nymphoides peltata	Rooted floating-

			leaved
Spirodela oligorrhiza	Free-floating	Myosotis laxa	Emergent
Spirodela polyrrhiza	Free-floating	Myosotis scorpioides	Emergent
Spirodela punctata	Free-floating	Heliotropium supinum	Emergent
Typhonodorum lindleyanum	Emergent	Rotula aquatica	Emergent
Wolffia arrhiza	Free-floating	Cardamine bonariensis	Emergent
Wolffia brasiliensis	Free-floating	Nasturtium officinale	Emergent
Wolffia globosa	Free-floating	Nasturtium microphyllum	Emergent
Wolffiella gladiata	Free-floating	Rorippa teres	Emergent
Wolffiella hyalina	Free-floating	Rorippa curvisiliqua	Emergent
Butomus junceus	Emergent	Rorippa tenerrima	Emergent
Butomus umbellatus	Emergent	Rorippa palustris	Emergent
Blyxa aubertii	Rooted submerged	Rorippa islandica	Emergent
Blyxa japonica	Rooted submerged	Rorippa amphibia	Emergent
Egeria densa	Rooted submerged	Centrostachys aquatica	Emergent
Elodea callitrichoides	Rooted submerged	Alternanthera ficoidea	Emergent
Elodea canadensis	Rooted submerged	Alternanthera philoxeroides	Emergent
Elodea nuttallii	Rooted submerged	Alternanthera sessilis	Emergent
Hydrilla verticillata	Rooted submerged	Aldrovanda vesiculosa	Free submerged
Hydrocharis dubia	Free-floating	Persicaria acuminata	Emergent
Hydrocharis morsus-ranae	Free-floating	Persicaria amphibia	Rooted floating-leaved
Lagarosiphon major	Rooted submerged	Persicaria arifolia	Emergent
Limnobium laevigatum	Free-floating	Persicaria decipiens	Emergent
Limnobium spongia	Free-floating	Persicaria glabra	Emergent
Limnobium spongia	Rooted floating-steamed	Persicaria hydropiper	Emergent
Najas gracillima	Rooted submerged	Persicaria hydropiperoides	Emergent
Najas graminea	Rooted submerged	Persicaria lapathifolia	Emergent
Najas guadalupensis	Free submerged	Persicaria limbata	Emergent
Najas marina	Rooted submerged	Persicaria maculosa	Emergent

Najas minor	Rooted submerged	Persicaria meisneriana	Emergent
Najas wrightiana	Rooted submerged	Persicaria punctata	Emergent
Najas wrightiana	Free submerged	Persicaria minor	Emergent
Ottelia alismoides	Rooted submerged	Persicaria sagittata	Emergent
Ottelia ovalifolia	Rooted floating-leaved	Persicaria senegalensis	Emergent
Stratiotes aloides	Rooted submerged	Rumex hydrolapathum	Emergent
Stratiotes aloides	Free submerged	Rumex aquaticus	Emergent
Stratiotes aloides	Emergent	Rumex britannica	Emergent
Vallisneria americana	Rooted submerged	Montia fontana	Rooted submerged
Vallisneria australis	Rooted submerged	Montia fontana	Emergent
Vallisneria nana	Rooted submerged	Montia parvifolia	Emergent
Vallisneria spiralis	Rooted submerged	Ceratophyllum demersum	Rooted submerged
Triglochin palustris	Emergent	Ceratophyllum muricatum	Rooted submerged
Triglochin bulbosa	Emergent	Ceratophyllum submersum	Rooted submerged
Triglochin scilloides	Rooted submerged	Hydrocera triflora	Emergent
Triglochin scilloides	Emergent	Lysimachia ciliata	Emergent
Hydrocleys nymphoides	Rooted floating-leaved	Lysimachia hybrida	Emergent
Limnocharis laforestii	Emergent	Lysimachia vulgaris	Emergent
Groenlandia densa	Rooted submerged	Hottonia palustris	Free-floating
Potamogeton acutifolius	Rooted submerged	Samolus ebracteatus	Emergent
Potamogeton crispus	Rooted submerged	Samolus valerandi	Emergent
Potamogeton diversifolius	Rooted submerged	Aeschynomene americana	Emergent
Potamogeton natans	Rooted floating-leaved	Aeschynomene aspera	Emergent
Potamogeton nodosus	Rooted floating-leaved	Aeschynomene evenia	Emergent
Potamogeton	Rooted	Aeschynomene indica	Emergent

perfoliatus	submerged		
Potamogeton polygonifolius	Rooted floating-leaved	Aeschynomene pratensis	Emergent
Potamogeton praelongus	Rooted submerged	Aeschynomene rudis	Emergent
Potamogeton pusillus	Rooted submerged	Aeschynomene sensitiva	Emergent
Potamogeton robbinsii	Rooted submerged	Aeschynomene virginica	Emergent
Potamogeton tricarinatus	Rooted floating-leaved	Neptunia oleracea	Emergent
Potamogeton trichoides	Rooted submerged	Neptunia oleracea	Rooted floating-steamed
Potamogeton vaseyi	Rooted floating-leaved	Neptunia plena	Emergent
Stuckenia pectinata	Rooted submerged	Vigna lasiocarpa	Emergent
Ruppia cirrhosa	Rooted submerged	Vigna lasiocarpa	Epiphytic
Ruppia cirrhosa	Emergent	Galium palustre	Emergent
Crinum americanum	Emergent	Oldenlandia capensis	Emergent
Iris brevicaulis	Emergent	Hygrophila costata	Emergent
Iris fulva	Emergent	Hygrophila difformis	Emergent
Iris hexagona	Emergent	Hygrophila difformis	Rooted submerged
Iris prismatica	Emergent	Hygrophila corymbosa	Emergent
Iris sanguinea	Emergent	Hygrophila corymbosa	Rooted submerged
Iris sibirica	Emergent	Hygrophila polysperma	Rooted submerged
Iris spuria	Emergent	Hygrophila triflora	Emergent
Iris pseudacorus	Emergent	Lycopus asper	Emergent
Iris setosa	Emergent	Lycopus europaeus	Emergent
Iris versicolor	Emergent	Mentha aquatica	Emergent
Commelina benghalensis	Emergent	Mentha arvensis	Emergent
Commelina communis	Emergent	Mentha longifolia	Emergent
Commelina diffusa	Emergent	Mentha pulegium	Emergent
Commelina erecta	Emergent	Mentha spicata	Emergent
Cyanotis axillaris	Emergent	Utricularia breviscapa	Free submerged
Cyanotis cucullata	Emergent	Utricularia geminiscapa	Free-floating
Floscopa glomerata	Emergent	Utricularia gibba	Free submerged
Murdannia keisak	Emergent	Utricularia subulata	Emergent

Murdannia nudiflora	Emergent	Glossostigma cleistanthum	Emergent
Murdannia spirata	Emergent	Glossostigma cleistanthum	Rooted submerged
Eichhornia azurea	Rooted floating-steamed	Mimulus ringens	Emergent
Eichhornia crassipes	Free-floating	Mimulus glabratus	Emergent
Eichhornia diversifolia	Rooted floating-steamed	Mimulus luteus	Emergent
Eichhornia paniculata	Emergent	Mimulus guttatus	Emergent
Heteranthera limosa	Rooted submerged	Bacopa caroliniana	Emergent
Heteranthera peduncularis	Rooted floating-steamed	Bacopa caroliniana	Rooted submerged
Heteranthera reniformis	Emergent	Bacopa egensis	Emergent
Heteranthera rotundifolia	Rooted floating-steamed	Bacopa egensis	Rooted submerged
Heteranthera rotundifolia	Emergent	Bacopa floribunda	Emergent
Heteranthera zosterifolia	Rooted submerged	Bacopa lanigera	Emergent
Monochoria korsakowii	Emergent	Bacopa monnieri	Emergent
Monochoria vaginalis	Emergent	Bacopa repens	Emergent
Pontederia cordata	Emergent	Bacopa rotundifolia	Rooted floating-steamed
Pontederia rotundifolia	Rooted floating-steamed	Callitriche brutia	Rooted submerged
Bolboschoenus glaucus	Emergent	Callitriche brutia	Rooted floating-leaved
Bolboschoenus maritimus	Emergent	Callitriche hermaphroditica	Rooted submerged
Bolboschoenus planiculmis	Emergent	Callitriche heterophylla	Rooted submerged
Bolboschoenus robustus	Emergent	Callitriche heterophylla	Rooted floating-leaved
Carex acuta	Emergent	Callitriche lechleri	Rooted submerged
Carex acutiformis	Emergent	Callitriche stagnalis	Rooted floating-leaved
Carex aquatilis	Emergent	Callitriche deflexa	Emergent
Carex canescens	Emergent	Callitriche marginata	Emergent

Carex crawfordii	Emergent	Callitriche terrestris	Emergent
Carex schweinitzii	Emergent	Callitriche nuttallii	Emergent
Carex shortiana	Emergent	Callitriche hamulata	Rooted submerged
Carex cuprina	Emergent	Callitriche hamulata	Rooted floating-leaved
Carex diluta	Emergent	Dopatrium junceum	Emergent
Carex disticha	Emergent	Gratiola aurea	Emergent
Carex heterostachya	Emergent	Hippuris vulgaris	Rooted submerged
Carex livida	Emergent	Hippuris vulgaris	Emergent
Carex paniculata	Emergent	Limnophila chinensis	Emergent
Carex rostrata	Emergent	Limnophila heterophylla	Emergent
Cyperus acuminatus	Emergent	Limnophila indica	Emergent
Cyperus aggregatus	Emergent	Limnophila sessiliflora	Rooted submerged
Cyperus alopecuroides	Emergent	Limosella aquatica	Emergent
Cyperus alternifolius	Emergent	Limosella aquatica	Rooted submerged
Cyperus amuricus	Emergent	Limosella australis	Emergent
Cyperus articulatus	Emergent	Veronica americana	Emergent
Cyperus compressus	Emergent	Veronica anagallis-aquatica	Emergent
Cyperus corymbosus	Emergent	Veronica beccabunga	Emergent
Cyperus cuspidatus	Emergent	Veronica catenata	Emergent
Cyperus difformis	Emergent	Veronica scutellata	Emergent
Cyperus digitatus	Emergent	Veronica undulata	Emergent
Cyperus distans	Emergent	Veronica anagalloides	Emergent
Cyperus eragrostis	Emergent	Lindernia crustacea	Emergent
Cyperus esculentus	Emergent	Lindernia diffusa	Emergent
Cyperus fuscus	Emergent	Lindernia dubia	Emergent
Cyperus glomeratus	Emergent	Lindernia procumbens	Emergent
Cyperus haspan	Emergent	Bergia capensis	Emergent
Cyperus imbricatus	Emergent	Elatine ambigua	Rooted submerged
Cyperus involucratus	Emergent	Elatine americana	Rooted submerged
Cyperus iria	Emergent	Elatine hungarica	Emergent
Cyperus laevigatus	Emergent	Elatine rubella	Emergent
Cyperus ligularis	Emergent	Elatine triandra	Emergent
Cyperus longus	Emergent	Caperonia castaneifolia	Emergent
Cyperus meyenianus	Emergent	Caperonia palustris	Emergent

Cyperus michelianus	Emergent	Caperonia palustris	Epiphytic
Cyperus mitis	Emergent	Phyllanthus fluitans	Free-floating
Cyperus ochraceus	Emergent	Torenia thouarsii	Emergent
Cyperus odoratus	Emergent	Ammannia auriculata	Emergent
Cyperus papyrus	Emergent	Ammannia baccifera	Emergent
Cyperus pectinatus	Emergent	Ammannia coccinea	Emergent
Cyperus pilosus	Emergent	Ammannia latifolia	Emergent
Cyperus procerus	Emergent	Ammannia robusta	Emergent
Cyperus prolifer	Emergent	Ammannia verticillata	Emergent
Cyperus prolixus	Emergent	Cuphea carthagenensis	Emergent
Cyperus reflexus	Emergent	Cuphea racemosa	Emergent
Cyperus rotundus	Emergent	Didiplis diandra	Rooted submerged
Cyperus rotundus	Epiphytic	Lythrum alatum	Emergent
Cyperus serotinus	Emergent	Lythrum hyssopifolia	Emergent
Cyperus sphacelatus	Emergent	Lythrum junceum	Emergent
Cyperus squarrosus	Emergent	Lythrum portula	Emergent
Cyperus strigosus	Emergent	Lythrum salicaria	Emergent
Cyperus surinamensis	Emergent	Lythrum borysthenicum	Emergent
Cyperus tenuiculmis	Emergent	Lythrum thymifolia	Emergent
Cyperus tenuispica	Emergent	Lythrum volgense	Emergent
Cyperus virens	Emergent	Lythrum tribracteatum	Emergent
Eleocharis acicularis	Emergent	Nesaea triflora	Emergent
Eleocharis acutangula	Emergent	Rotala densiflora	Emergent
Eleocharis atropurpurea	Emergent	Rotala filiformis	Emergent
Eleocharis dulcis	Emergent	Rotala indica	Emergent
Eleocharis erythropoda	Emergent	Rotala mexicana	Emergent
Eleocharis exigua	Emergent	Rotala mexicana	Rooted submerged
Eleocharis flavescens	Emergent	Rotala ramosior	Emergent
Eleocharis geniculata	Emergent	Rotala rotundifolia	Emergent
Eleocharis macrostachya	Emergent	Rotala rotundifolia	Rooted submerged
Eleocharis bonariensis	Emergent	Trapa natans	Rooted floating-leaved
Eleocharis nigrescens	Emergent	Epilobium ciliatum	Emergent
Eleocharis obtusa	Emergent	Epilobium coloratum	Emergent
Eleocharis ochrostachys	Emergent	Epilobium cylindricum	Emergent

Eleocharis pachycarpa	Emergent	Epilobium hirsutum	Emergent
Eleocharis palustris	Emergent	Epilobium parviflorum	Emergent
Eleocharis parvula	Emergent	Ludwigia adscendens	Emergent
Eleocharis parvula	Rooted submerged	Ludwigia adscendens	Rooted floating-steamed
Eleocharis retroflexa	Emergent	Ludwigia decurrens	Emergent
Eleocharis schaffneri	Emergent	Ludwigia grandiflora	Emergent
Eleocharis parodii	Emergent	Ludwigia longifolia	Emergent
Eleocharis wolfii	Emergent	Ludwigia erecta	Emergent
Fimbristylis aestivalis	Emergent	Ludwigia hyssopifolia	Emergent
Fimbristylis alboviridis	Emergent	Ludwigia leptocarpa	Emergent
Fimbristylis aphylla	Emergent	Ludwigia octovalvis	Emergent
Fimbristylis autumnalis	Emergent	Ludwigia palustris	Emergent
Fimbristylis bisumbellata	Emergent	Ludwigia palustris	Rooted submerged
Fimbristylis complanata	Emergent	Ludwigia peploides	Emergent
Fimbristylis cymosa	Emergent	Ludwigia perennis	Emergent
Fimbristylis dichotoma	Emergent	Ludwigia peruviana	Emergent
Fimbristylis ferruginea	Emergent	Ludwigia polycarpa	Emergent
Fimbristylis griffithii	Emergent	Ludwigia prostrata	Emergent
Fimbristylis littoralis	Emergent	Ludwigia repens	Rooted floating-steamed
Fimbristylis ovata	Emergent	Ludwigia affinis	Emergent
Fimbristylis quinquangularis	Emergent	Cabomba caroliniana	Rooted submerged
Fimbristylis squarrosa	Emergent	Cabomba furcata	Rooted submerged
Fimbristylis umbellaris	Emergent	Cabomba haynesii	Rooted submerged
Fimbristylis vahlii	Emergent	Cabomba paliformis	Rooted submerged
Fuirena ciliaris	Emergent	Nuphar advena	Rooted floating-leaved
Fuirena cuspidata	Emergent	Nuphar advena	Rooted floating-steamed
Fuirena pubescens	Emergent	Nuphar japonica	Rooted floating-leaved
Fuirena scirpoidea	Emergent	Nuphar lutea	Rooted floating-

			leaved
Isolepis cernua	Emergent	Nuphar pumila	Rooted floating-leaved
Isolepis setacea	Emergent	Nuphar rubrodisca	Rooted floating-leaved
Isolepis fluitans	Emergent	Nymphaea alba	Rooted floating-leaved
Kyllinga brevifolia	Emergent	Nymphaea capensis	Rooted floating-leaved
Kyllinga gracillima	Emergent	Nymphaea elegans	Rooted floating-leaved
Kyllinga melanosperma	Emergent	Nymphaea lotus	Rooted floating-leaved
Kyllinga odorata	Emergent	Nymphaea mexicana	Rooted floating-leaved
Kyllinga squamulata	Emergent	Nymphaea nouchali	Rooted floating-leaved
Lagenocarpus guianensis	Emergent	Nymphaea odorata	Rooted floating-leaved
Lepironia articulata	Emergent	Nymphaea rubra	Rooted floating-leaved
Lipocarpha maculata	Emergent	Houttuynia cordata	Emergent
Lipocarpha micrantha	Emergent	Saururus cernuus	Emergent
Oxycaryum cubense	Epiphytic	Nelumbo lutea	Rooted floating-leaved
Pycreus flavescens	Emergent	Nelumbo nucifera	Emergent
Pycreus lanceolatus	Emergent	Caltha palustris	Emergent
Pycreus macrostachyos	Emergent	Myosurus minimus	Emergent
Pycreus mundii	Emergent	Ranunculus flammula	Emergent
Pycreus polystachyos	Emergent	Ranunculus hederaceus	Rooted submerged
Pycreus pumilus	Emergent	Ranunculus hederaceus	Emergent
Pycreus flavidus	Emergent	Ranunculus lingua	Emergent
Pycreus sanguinolentus	Emergent	Ranunculus penicillatus	Rooted submerged
Pycreus unioloides	Emergent	Ranunculus multifidus	Emergent
Rhynchospora corymbosa	Emergent	Ranunculus lateriflorus	Emergent
Rhynchospora tenuis	Emergent	Ranunculus ophioglossifolius	Emergent
Schoenoplectiella erecta	Emergent	Ranunculus ophioglossifolius	Rooted submerged
Schoenoplectiella	Emergent	Ranunculus reptans	Emergent

juncoides			
Schoenoplectiella lateriflora	Emergent	Ranunculus repens	Emergent
Schoenoplectiella lineolata	Emergent	Ranunculus sceleratus	Emergent
Schoenoplectiella mucronata	Emergent	Ranunculus trichophyllus	Rooted submerged
Schoenoplectiella supina	Emergent	Ranunculus trichophyllus	Emergent
Schoenoplectus californicus	Emergent	Halerpestes cymbalaria	Emergent
Schoenoplectus lacustris	Emergent	Myriophyllum aquaticum	Emergent
Schoenoplectus smithii	Emergent	Myriophyllum crispatum	Rooted submerged
Schoenoplectus tabernaemontani	Emergent	Myriophyllum crispatum	Emergent
Schoenoplectus triqueter	Emergent	Myriophyllum heterophyllum	Rooted submerged
Schoenus apogon	Emergent	Myriophyllum hippuroides	Rooted submerged
Scirpoides holoschoenus	Emergent	Myriophyllum humile	Emergent
Scirpus cyperinus	Emergent	Myriophyllum humile	Rooted submerged
Scleria gaertneri	Emergent	Myriophyllum pinnatum	Emergent
Scleria lacustris	Emergent	Myriophyllum pinnatum	Rooted submerged
Eriocaulon truncatum	Emergent	Myriophyllum quitense	Rooted submerged
Eriocaulon cinereum	Rooted submerged	Myriophyllum sibiricum	Rooted submerged
Eriocaulon cinereum	Emergent	Myriophyllum simulans	Rooted submerged
Eriocaulon decangulare	Emergent	Myriophyllum simulans	Emergent
Eriocaulon melanocephalum	Rooted submerged	Myriophyllum spicatum	Rooted submerged
Juncus anthelatus	Emergent	Myriophyllum spicatum	Emergent
Juncus brachycarpus	Emergent	Proserpinaca intermedia	Emergent
Juncus brevicaudatus	Emergent	Crassula aquatica	Emergent
Juncus articulatus	Emergent	Crassula aquatica	Rooted submerged
Juncus bufonius	Emergent	Crassula helmsii	Emergent
Juncus bulbosus	Emergent	Crassula helmsii	Rooted

			submerged
Juncus diffusissimus	Emergent	Crassula natans	Emergent
Juncus effusus	Emergent	Crassula natans	Rooted floating-steamed
Juncus hybridus	Emergent	Crassula peduncularis	Emergent
Juncus inflexus	Emergent	Crassula vaillantii	Emergent
Juncus microcephalus	Emergent	Ipomoea alba	Emergent
Juncus oxycarpus	Emergent	Ipomoea alba	Epiphytic
Juncus pelocarpus	Emergent	Ipomoea aquatica	Emergent
Juncus subnodulosus	Emergent	Ipomoea asarifolia	Emergent
Juncus ensifolius	Emergent	Ipomoea carnea	Emergent
Juncus conglomeratus	Emergent	Ipomoea carnea	Epiphytic
Juncus dregeanus	Emergent	Sphenoclea zeylanica	Emergent
Juncus lomatophyllus	Emergent	Hydrolea spinosa	Emergent
Juncus striatus	Emergent	Hydrolea zeylanica	Emergent
Mayaca fluviatilis	Rooted submerged	Stellaria aquatica	Emergent
Agrostis perennans	Emergent	Illecebrum verticillatum	Emergent
Agrostis lachnantha	Emergent	Illecebrum verticillatum	Rooted submerged
Agrostis stolonifera	Emergent	Hypericum elodes	Emergent
Amphibromus fluitans	Emergent	Hypericum mutilum	Emergent
Beckmannia eruciformis	Emergent	Corrigiola litoralis	Emergent
Beckmannia syzigachne	Emergent	Ranunculus japonicus	Emergent
Catabrosa aquatica	Emergent	Trapa natans var. bispinosa	Rooted floating-leaved
Saccharum ravennae	Emergent	Nymphaea nouchali var. caerulea	Rooted floating-leaved
Saccharum spontaneum	Emergent	Angelica pachycarpa	Emergent
Sacciolepis indica	Emergent	Carex viridula subsp. oedocarpa	Emergent
Sacciolepis striata	Emergent	Isolepis cernua var. platycarpa	Emergent
Scolochloa festucacea	Emergent	Montia fontana subsp. chondrosperma	Rooted submerged
Spartina pectinata	Emergent	Montia fontana subsp. chondrosperma	Emergent
Chrysopogon	Emergent	Spartina townsendii	Emergent

nigritanus			
Chrysopogon zizanioides	Emergent	Nymphaea marliacea	Rooted floating-leaved
Zizania aquatica	Emergent	Typha glauca	Emergent
Zizania latifolia	Emergent	Halophila stipulacea	Rooted submerged
Zizania palustris	Emergent	Althaea longiflora	Emergent
Acroceras macrum	Emergent	Potamogeton fluitans	Rooted floating-leaved
Acroceras zizanioides	Emergent	Zostera noltii	Rooted submerged
Alopecurus aequalis	Emergent	Salvinia olfersiana	Free-floating
Alopecurus geniculatus	Emergent	Eleocharis mamillata subsp. austriaca	Emergent
Alopecurus longiaristatus	Emergent	Ludwigia peploides subsp. montevidensis	Emergent
Arundo donax	Emergent	Smilax rotundifolia	Emergent
Brachiaria arrecta	Emergent	Smilax rotundifolia	Epiphytic
Brachiaria arrecta	Rooted floating-steamed	Typha provincialis	Emergent
Brachiaria eruciformis	Emergent	Cladium mariscus subsp. jamaicense	Emergent
Brachiaria mutica	Emergent	Juncus effusus subsp. solutus	Emergent
Brachiaria subquadripara	Emergent	Zizania aquatica var. interior	Emergent
Brachiaria fasciculata	Emergent	Limnophila ludoviciana	Emergent
Dimeria ornithopoda	Emergent	Najas guadalupensis subsp. olivacea	Free submerged
Echinochloa colona	Emergent	Cyperus michelianus subsp. pygmaeus	Emergent
Echinochloa crus-galli	Emergent	Halophila decipiens	Rooted submerged
Echinochloa crus-pavonis	Emergent	Anemopsis californica	Emergent
Echinochloa holciformis	Emergent	Chloracantha spinosa	Emergent
Echinochloa oryzoides	Emergent	Ludwigia peploides var. glabrescens	Emergent
Echinochloa polystachya	Rooted floating-steamed	Persicaria amphibia var. natans	Rooted floating-leaved
Echinochloa pyramidalis	Emergent	Cullen americanum	Emergent
Echinochloa stagnina	Emergent	Nymphaea daubeniana	Rooted floating-leaved

Echinochloa walteri	Emergent	Ludwigia kentiana	Emergent
Glyceria arkansana	Emergent	Ludwigia kentiana	Rooted submerged
Glyceria canadensis	Emergent	Eleocharis flavescens var. olivacea	Emergent
Glyceria declinata	Emergent	Potamogeton undulatus	Rooted submerged
Glyceria fluitans	Emergent	Nymphaea thiona	Rooted floating-leaved
Glyceria grandis	Emergent	Artemisia codonocephala	Emergent
Glyceria maxima	Emergent	Astragalus uliginosus	Emergent
Glyceria notata	Emergent	Nymphaea odorata subsp. tuberosa	Rooted floating-leaved
Glyceria septentrionalis	Emergent	Cyperus nutans var. eleusinoides	Emergent
Glyceria striata	Emergent	Dentella repens var. serpyllifolia	Emergent
Gynerium sagittatum	Emergent	Halodule wrightii	Rooted submerged
Helictotrichon neesii	Emergent	Juncus acutus subsp. leopoldii	Emergent
Hymenachne amplexicaulis	Rooted floating-steamed	Ludwigia adscendens subsp. diffusa	Emergent
Isachne globosa	Emergent	Ludwigia adscendens subsp. diffusa	Rooted floating-steamed
Ischaemum latifolium	Emergent	Juncus castaneus	Emergent
Ischaemum rugosum	Emergent	Ceratophyllum muricatum subsp. australe	Rooted submerged
Leersia hexandra	Emergent	Lycopodiella caroliniana var. meridionalis	Emergent
Leersia oryzoides	Emergent	Sagittaria lancifolia subsp. media	Emergent
Leptochloa fusca	Emergent	Ranunculus aquatilis var. diffusus	Rooted submerged
Leptochloa panicea	Emergent	Ranunculus aquatilis var. diffusus	Emergent
Leptochloa scabra	Emergent	Sagittaria montevidensis subsp. calycina	Emergent
Luziola peruviana	Emergent	Arundinaria gigantea subsp. tecta	Emergent
Luziola subintegra	Emergent	Posidonia oceanica	Rooted submerged
Oryza glaberrima	Emergent	Pluchea rufescens	Emergent
Oryza latifolia	Emergent	Nymphaea lotus var.	Rooted floating-

		thermalis	leaved
Oryza rufipogon	Emergent	Angelica purpurascens	Emergent
Oryza sativa	Emergent	Limnophila rugosa	Emergent
Panicum aquaticum	Emergent	Crassula natans var. minus	Emergent
Panicum dichotomiflorum	Emergent	Crassula natans var. minus	Rooted floating-steamed
Panicum gilvum	Emergent	Cyperus digitatus subsp. auricomus	Emergent
Panicum laxum	Emergent	Pontederia reniformis	Rooted floating-steamed
Panicum maximum	Emergent	Paspalum geminatum	Emergent
Panicum mertensii	Emergent	Austroderia richardii	Emergent
Panicum paludosum	Rooted floating-steamed	Batrachium trichophyllum	Rooted submerged
Panicum paludosum	Emergent	Carex viridula subsp. brachyrhyncha	Emergent
Panicum repens	Emergent	Cladium mariscus subsp. intermedium	Emergent
Panicum sumatrense	Emergent	Cladium tetraquetrum var. planifolium	Emergent
Panicum subalbidum	Emergent	Polygonum thunbergii	Emergent
Paspalidium geminatum	Emergent	Asclepias incarnata subsp. pulchra	Emergent
Paspalum acuminatum	Emergent	Cyperus sumatrensis	Emergent
Paspalum distichum	Emergent	Ludwigia arcuata x repens	Emergent
Paspalum fasciculatum	Emergent	Ludwigia arcuata x repens	Rooted floating-steamed
Paspalum modestum	Emergent	Schoenoplectus glaucus	Emergent
Paspalum notatum	Emergent	Glyceria pedicellata	Emergent
Paspalum quadrifarium	Emergent	Eriocaulon benthamii	Emergent
Paspalum scrobiculatum	Emergent	Schoenoplectus kuekenthalianus	Emergent
Paspalum vaginatum	Emergent	Callitriche peploides	Emergent
Paspalum virgatum	Emergent	Hygrophila stricta	Emergent

APPENDIX D – Native species per region

Note: Readers can request to the corresponding author the full data set and all scripts regarding data manipulation and analysis.

Table D1 - Top 10 regions ranked according to the number of native species in each region (upper section) and according to the species-area ratio (bottom section). Regions are named according to the TDWG scheme (Brummitt et al., 2001) level 4. Country names are extracted from GloNAF database. N. of Species is the count of native species in each region; Spec./Area is the ratio between the number of native species and the area (in km2) of each polygon (van Kleunen et al., 2019). Type column identifies island and mainland regions. Region column shows the identity of each area (polygon) in the dataset.

Regions ranked considering the absolute number of native species				
TDWG4 Region	**Country**	**N. of Species**	**Type**	**Region**
Bolivia	Bolivia	191	Mainland	151
Veracruz	Mexico	179	Mainland	474
Italy	Italy	172	Mainland	411
Texas	United States of America	171	Mainland	797
Colombia	Colombia	170	Mainland	306
France	France	168	Mainland	340
Macedonia	Macedonia	165	Mainland	481
Peru	Peru	165	Mainland	530
Japan	Japan	164	Island	416
Yunnan	China	162	Mainland	277
Regions ranked considering the species-area ratio Regions				
TDWG4 Region	**Country**	**N. of Species/Km²**	**Type**	**Region**
Seychelles	Seychelles	43.71	Island	707
Seychelles	Seychelles	28.61	Island	680
Seychelles	Seychelles	18.43	Island	692
Samoa	Samoa	16.63	Island	814
Seychelles	Seychelles	16.31	Island	705
Seychelles	Seychelles	9.53	Island	719
Seychelles	Seychelles	8.52	Island	690
Macau	Macao	8.49	Mainland	284
Seychelles	Seychelles	8.39	Island	683
Seychelles	Seychelles	6.75	Island	718

4 GENERAL CONCLUSION

The two approaches of this thesis represent advances in the study of the ecology of aquatic macrophyte invasion both locally and globally. Analyzing the introduction and expansion of *H. verticillata*, it is noted that this species does not represent a substantial threat to the upper Paraná river floodplain (UPRF). This finding is valuable for managers with a limited amount of resources since the management of this species is very costly and practically impossible in large areas such as UPRF. The monitoring used showed evidence of anthropogenic changes in the abiotic conditions of environments not colonized by *H. verticillata* at first, but which, over time, proved to be favorable for its establishment. Such evidence leads us to the conclusion that constant monitoring of *H. verticillata* and abiotic conditions in the face of anthropogenic impacts is necessary. However, managers working in UPRF or other floodplains with a similar situation should consider monitoring studies to assess the lack of impact, or even the positive interactions of this species, before spending on management strategies.

Globally, this study contributes a valuable dataset that can be used by local managers in different locations around the world. It has been shown that most introductions of aquatic macrophyte species occur via intentional introduction pathways, which are easier to contain. As this work progressed by identifying such pathways, as well as the potential source and sink regions for naturalized macrophyte species, a tool is created for managers and decision-makers related to aquatic environments. Our results could be used to prevent introductions of species into progress, or even anticipate such introductions. The data set, as well as the scripts used in the analizes can be requested from the corresponding author.