*Tropical Ecology* **55**(2): 143-157, 2014 ISSN 0564-3295

www.tropecol.com

# Characterization of alien aquatic flora of Kashmir Himalaya: implications for invasion management

MANZOOR A. SHAH* & ZAFAR A. RESHI

*Biological Invasion Laboratory, Department of Botany, University of Kashmir, Srinagar 190 006, India*

**Abstract:** Wide information gaps in invasive species research in the developing world create important bottlenecks in synthesis of the global status and trends of alien plant invasions. The objective of the present study was to reduce such information gaps through an inventory and stage-based characterization of the alien aquatic flora of Kashmir Himalaya with potential management implications. After comprehensive literature scanning, thorough field surveys were undertaken in freshwater lakes, wetlands, rivers and other aquatic habitats of the Kashmir Himalaya for inventorying the alien flora. For assessing current invasion status, the species were categorized into different stages of invasion on the basis of the extent of spatial spread measured in terms of the frequency and cover percentage across sites. Species nativity was established through standard floras and web-based sources. Results yielded 129 alien plant species belonging to 68 genera and 42 families, representing four major life forms including emergents (69.1 %), rooted floating leaf types (15.6 %), submerged types (10.1 %), and free floating types (7 %). Majority of alien plant species are native to Europe (63 %), followed by North America (14 %), Asia (12 %), South America (4 %), Australia, and Africa (3 %) each. Cyperaceae (22 spp.) and Potamogetonaceae (10 spp.) were the two most species-rich families followed by Polygonaceae (8 spp.), and Lemnaceae (7 spp.). *Potamogeton* and *Cyperus* with ten species each were the two largest genera. The Colautti and MacIsaac model was tested for classification of alien species into different stages of invasion, which yielded 16 species at Stage IVa (widespread but rare), 26 species at Stage IVb (localized but dominant), and 29 species at Stage V (widespread and dominant). This baseline dataset reasonably bridges the knowledge gap in the global database of invasive species from Asia and provides useful management implications for invasive species.

**Resumen:** Los grandes vacíos de información en la investigación sobre especies invasoras en el mundo en desarrollo creancuellos de botella importantesparala síntesis del estatus y las tendencias mundiales en las invasiones de plantas exóticas. El objetivode esteestudiofue reducir estos vacíos de información através de un inventarioy unacaracterización basada en las etapasde invasión de la flora acuática exóticade los Himalaya de Cachemiracon implicaciones potenciales de manejo. A partir de una revisión amplia de la literatura, se hicieronprospecciones de campo completas en lagos de agua dulce, humedales, ríosy otroshábitats acuáticosde la región para elaborar el inventario de la flora exótica. Para evaluar el estatus actual de la invasión,lasespecies fueron categorizadasen diferentes etapas de la invasióncon base enla extensiónespacial medida en términos de la frecuenciay porcentaje decobertura en los sitios. Se estableció el carácter nativo de las especies por medio defloras estándar y fuentes en la red. Los resultados produjeron una lista de 129 especies de plantas exóticas pertenecientes a 68 géneros y 42 familias, con representantesde cuatro formas de vida principales incluyendo emergentes (69.1 %), tipos enraizados con hojas flotantes (15.6 %), tipos sumergidos (10.1 %) ytipos libre flotadores (7 %). La mayoríade las plantas exóticas son nativasde Europa (63 %), seguidasde

**Corresponding Author*; e-mail: mashah75@yahoo.com

Norteamérica (14 %), Asia (12 %), Sudamérica (4 %), Australia y África (3 %). Cyperaceae (22 especies) y Potamogetonaceae (10) fueron las dos familias más ricas en especies, seguidas por Polygonaceae (8 especies) y Lemnaceae (7). *Potamogeton* y *Cyperus*, con 10 especies cada uno, fueron los dos géneros más grandes. Se puso a prueba el modelo de Colauttiy MacIsaacpara clasificar las especies exóticasen diferentes etapas de invasión, lo cual resultó en 16 especies en la Etapa IVa (distribución amplia, perorara), 26 especies en la Etapa IVb (distribución localizadapero dominante) y 29 especies en la Etapa V (distribución ampliay dominante). Esta información básicaresuelve razonablementeel vacío deconocimientoen la base de datos mundial de especies invasoras de Asia y proporciona implicaciones útiles para el manejo de especies invasoras.

**Resumo:** Grandeslacunas de informaçãona investigação sobre espécies invasoras no mundo em desenvolvimento criamestrangulamentos importantes na síntese do estado e das tendências globais da invasão de plantas exóticas. O objetivo do presente estudo foi pois o de reduzir essas lacunas de informação através de um inventário e caracterização baseada no estado da flora aquática exótica da Caxemira Himalaia, com potenciais implicações para a gestão. Após a exploraçãosistemática da literatura, foram realizadas pesquisas intensivasde campo para inventariar a flora exótica em lagos de água doce, rios, pântanos e outros habitats aquáticos da Caxemira Himalaia. Para avaliar o estado atualda invasão, as espécies foram categorizadas em diferentes fases de invasão tendo por base a extensão da distribuição espacial, medida em termos de frequência e percentagem de cobertura entre os locais. As espécies nativas foram estabelecidas através de floras padrão e fontes de informação baseadas na internet. Os resultados obtidos identificaram 129 espécies de plantas exóticas pertencentes a 68 géneros e 42 famílias, representando quatro grandes formas de vida, incluindo as emergentes (69,1 %), as do tipoenraizadas de folhas flutuantes (15,6 %), tipos submersas (10,1 %), e os tipos flutuantes livres (7 %). A maioria das espécies de plantas exóticas são nativas da Europa (63 %), seguidas pelas da América do Norte (14 %), Ásia (12 %), América do Sul (4 %), Austrália e África (3 %). As Ciperáceas (22 spp.) e as Potamogetonaceae (10 spp.) foram as duas famílias mais ricas em espécies seguidaspelas Polygonaceae (8 spp.), e Lemnaceae (7 spp.). As *Potamogeton* e *Cyperus*, cada umacom dez espécies, foram os dois maiores géneros. O modelo de Colautti e MacIsaac foi testado para a classificação de espécies exóticas em diferentes estágios de invasão, que apontou 16 espécies noestágio IVa (generalizada, mas rara), 26 espécies no estágio IVb (localizada, mas dominante), e 29 espécies na estágio V (generalizada e dominante). Este conjunto de dados de base preenche razoavelmente a lacuna de conhecimento no banco de dados global quanto às espécies invasoras da Ásia e fornece informaçõesúteis para a gestão das espécies invasoras.

**Key words:** Alien plant species, aquatic ecosystems, Colautti MacIsaac model, Kashmir Himalaya, plant invasion.

## Introduction

Introduction of species from their native regions to new and previously unoccupied areas, intentionally or unintentionally, dates back to the times when humans started traveling over and between land masses (Elton 1958). However, rapid globalization and fast growing transnational trade and commerce have exacerbated the rate and magnitude of alien species introductions several fold, thereby making it a cause of ecological concern globally. The spread of invasive species beyond their home range has many underlying mechanisms (reviewed by Catford *et al.* 2008), and such species are generally detrimental to native biodiversity and ecosystem functioning in the introduced regions, inflicting huge socio-economic damage (Pimentel *et al.* 2005).

Notwithstanding that freshwater ecosystems provide a range of valuable economic goods and irreplaceable ecosystem services for humanity, aquatic biodiversity is increasingly threatened by overexploitation, pollution, hydrological fluctuations, habitat degradation, and invasion by alien species

(Dudgeon *et al.* 2006; Perbiche-Neves *et al.* 2012). Of these and other threats, biological invasion has emerged as the most severe one (Olden *et al.* 2006; Zedler & Kercher 2004) causing substantial damage with cascading effects on structural organization and functional integrity of freshwater ecosystems. There is reportedly more decline and extinction of species in freshwater ecosystems than in terrestrial or marine environments due to biological invasions (Olden *et al.* 2006). The United Nation's International Decade (2005 to 2015) for Action - '*Water for Life*' - which prioritizes concern for freshwater biodiversity conservation, makes assessment of aquatic invasions, their well-timed prediction, and effective management even more important.

Aquatic habitats, especially lakes and wetlands, being resource rich, are highly vulnerable to invasion (Zedler & Kercher 2004). Moreover, many aquatic plants are characteristically invasive due to their immense potential of rapidly increasing their spatial distribution (Richardson *et al.* 2000). Many correlates can be drawn between a suite of environmental conditions and aquatic invasions (Ehrenfeld 2008), with promising implications for management of invasive species in the context of growing urbanization and anthropogenic disturbances. Recently, attempts have been made to link plant invasion to environmental pollution (Hiremath & Agrawal 2010) and, in view of the growing water pollution, e.g., eutrophication, incidence of plant invasions is likely to increase as well (Drexler & Bedford 2002). But fundamental to all efforts for prediction and management of invasions is to have an inventory of the alien species and their distribution pattern. Even more important from a management perspective is the stage-based characterization of alien flora, because invasion is a stage-wise process, species vary in their extent of spatial spread and abundance, and hence require different management tools and strategies. One such workable stage-based hierarchical model (hereafter, the CM model) was proposed by Colautti & MacIsaac (2004). The CM model describes seven stages (0, I, II, III, IVa, IVb, and V) which are reflective of the sequential series of steps involved in the process of biological invasions. The CM model has been successfully tested by some workers (Khuroo *et al.* 2008; Lawes *et al.* 2006; Shah *et al.* 2011), though more studies need to test the model for its robustness and wide-scale applicability to take it forward from its stage of scientific infancy.

The status and distribution of wetlands in India (with an estimated area of 58.2 million hectares) and their plant biodiversity have been documented, and causes and consequences of wetland losses have been reviewed (Pradhan *et al.* 2005; Prasad *et al.* 2002). However, invasion as a threat to wetlands is almost ignored. Hence, a preliminary conspectus of alien flora invading Indian aquatic systems has been recently attempted by the authors (Shah & Reshi 2012). Kashmir Himalayan region, owing to its characteristic geological history and eco-climatic regimes, abounds in a myriad of freshwater ecosystems that are rich repositories of native biodiversity (Khan *et al.* 2004). It is pertinent to mention here that freshwater ecosystems comprise the backbone of Kashmir Himalayan scenic beauty, local economy, and ecotourism potential. However, cumulative invasions have disproportionately transformed most of these ecosystems from diverse and heterogeneous to almost homogenous systems (Reshi *et al.* 2008), thereby telling upon their aesthetic and ecological value. The spatial spread of alien species, at the cost of traditionally valued native species, has been locally exacerbated by mounting anthropogenic disturbance of freshwater habitats. While the documentation of the terrestrial alien flora of the region has been attempted (Khuroo *et al.* 2007), there is an obvious knowledge gap due to lack of information on aquatic invasions. Hence, the specific objectives of the present study were (a) creation of a well annotated database of aquatic alien flora of Kashmir Himalaya, and (b) testing the CM model for stage-based characterization of the documented flora. The baseline information generated in this study is likely to trigger rigorous hypothesis testing through more advanced studies to enrich the global invasion ecology literature with useful insights from this part of the world.

## Material and methods

### *Study area*

The Kashmir Himalaya region (32° 20' to 34° 50' N and 73° 35' to 75° 55' E) includes parts of the Pirpanjal range of Lesser Himalaya in the south and south-west and the Zanskar range of Greater Himalaya in the north and north-east. The region has an area of about 15,948 km$^2$ within a large altitudinal range of 1,600 m to 5,420 m amsl. In fact, the valley of Kashmir is a lacustrine basin of the intermontane depression existing between the Lesser and the Greater Himalaya and abounds with numerous freshwater ecosystems. Particu-

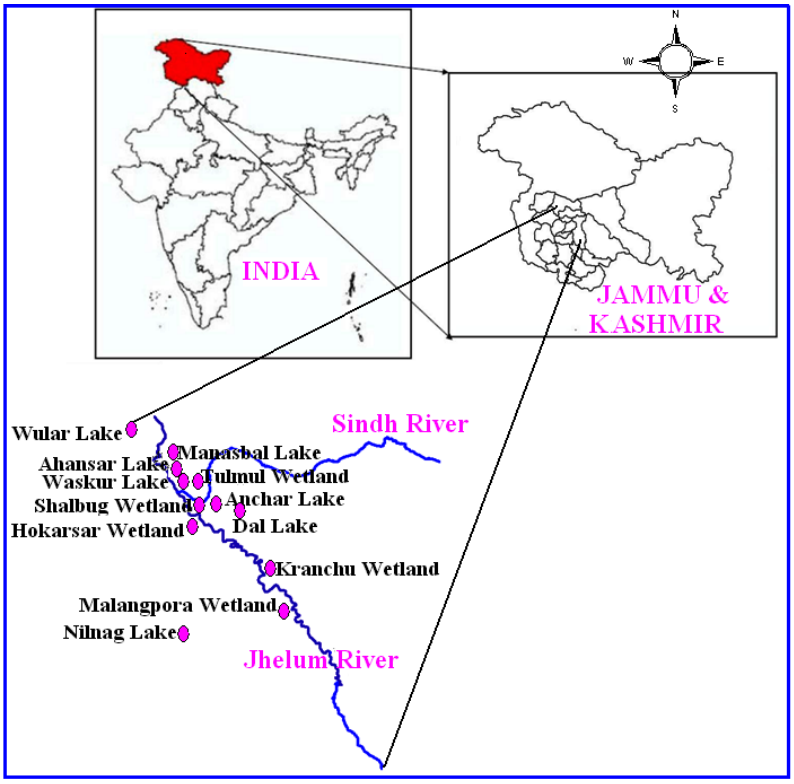


**Fig. 1.** Study area showing location of the aquatic ecosystems surveyed in the Kashmir Himalaya during the present study for occurrence and distribution pattern of alien plant species.

**Table 1.** Brief description of the investigated aquatic ecosystems (lakes, wetlands and rivers) as habitats of documented alien plant species. The systems varied in trophic status along an oligotrophic-mesotrophic-eutrophic gradient within an altitudinal range of 1580-2180 m asl.

| Waterbody | Geographic Coordinates | | | Area | Depth (m) | Trophic Status | Secchi |
|---|---|---|---|---|---|---|---|
| | Latitude | Longitude | Altitude | ($km^2$) | | | Transp-arency (m) |
| Ahansar lake | 34-13' 44 | 74-39' 41 | 1583 | 0.8 | 3.6 | Low-eutrophic | 2.9 |
| Anchar lake | 34-09' 22 | 74-4'7 30 | 1584 | 2.75 | 1.3 | Eutrophic | 1.1 |
| Dal lake | 34-07' 55 | 74-51' 21 | 1584 | 10.5 | 0.9 | Eutrophic | 0.4 |
| Manasbal lake | 34-14' 52 | 74-40' 07 | 1583 | 2.8 | 4.5 | Low-eutrophic | 3.5 |
| Nilnag lake | 33-51' 22 | 74-41' 36 | 2180 | 0.5 | 5.5 | Oligotrophic | 4.5 |
| Narangbagh lake | 34-58' 49 | 74-51' 19 | 1587 | 0.24 | 3.4 | Mesotrophic | 2.8 |
| Waksar lake | 34-13' 06 | 74-39' 40 | 1590 | * | 4.3 | Low-eutrophic | 3.2 |
| Wular lake | 34-20' 08 | 74-32' 54 | 1580 | 21 | 3 | Eutrophic | 1.5 |
| Hokersar wetland | 34-06' 02 | 74-43' 08 | 1584 | 7.5 | 0.7 | Low-eutrophic | 0.3 |
| Kranchu wetland | 33-59' 49 | 74-56' 19 | 1588 | 0.36 | 0.2 | Mesotrphic | 0.1 |
| Malangpora wetland | 33-53' 58 | 74-58' 55 | 1600 | 1.0 | 0.3 | Mesotrophic | 0.1 |
| Shallabugh wetland | 34-09' 12 | 74-44' 14 | 1580 | 5.0 | 0.7 | Eutrophic | 0.3 |
| Tulmula wetland | 34-12' 41 | 74-43' 51 | 1610 | 2.0 | 0.8 | Mesotrphic | 0.3 |
| Jehlum river | 33-32' to 34-22' N | 74-36' to 75-14' E | * | * | * | Eutrophic | * |
| Sindh river | 34-11' to 34-15' N | 74-40' to 75-25'E | * | * | * | Mesotrphic | * |

Note : * Refers to unavailable data for lakes and wetlands; for rivers (Jehlum and Sindh) the data are not applicable as for the rest of the water bodies.

larly due to undulating topography and characteristically snow capped mountains and hills, together with its unique geographical location, eco-climatic conditions, and edaphic characteristics, the valley harbours heterogeneous lakes, wetlands, springs, rivers, and streams ranging from subtropical, temperate, subalpine to alpine types along an altitudinal gradient. The valley largely experiences a sub-Mediterranean type of climate with relatively hot summers and cold winters. The average maximum temperature fluctuates from 15°C to 33°C and minimum from and -4°C to 4°C.

The waterbodies selected for this study were chosen on the basis of their representative character (both lotic and lentic systems), trophic status gradient (ranging from oligotrophy to eutrophy), and inclusion of the two major Ramsar Sites (Lake Wular and Hokersar Wetland) of the region (Fig. 1, Table 1). It is pertinent to mention that lentic waterbodies are more prone to invasion than lotic waterbodies due to less resilience and more residence time and concentration of nutrients and other pollutants in the former (Zedler & Kercher 2004). Similarly, eutrophic systems are more vulnerable to invasion than oligotrophic systems because invasive species, being ruderals, proliferate rapidly in nutrient rich environments (Drexler & Bedford 2002).

### *Survey and documentation*

We began the documentation of alien aquatic flora through survey of relevant literature including journals, scientific reports, weed floras, policy documents, herbarium specimens, and other published and unpublished records. The most important sources of information about the occurrence of alien species in Kashmir Himalayan aquatic systems included Kaul *et al.* (1973), Zutshi (1975), Kak & Javeid (1976), Naqshi (1981), Reshi (1984), Kak (1984), Kaul (1986), Kundangar & Zutshi (1987), Koul & Naqshi (1988), Kak (1990), Cook (1996), Khan *et al.* (2004), Khuroo *et al.* (2007), Reshi *et al.* (2008), Shah *et al.* (2011). From these sources information was retrieved about the occurrence, abundance and distribution pattern of plant species in the select waterbodies. For authentication of taxonomic identification of the species standard sources such as Hooker's Magnum Opus, the *Flora of British India* (1872-1897), Stewart (1972), Kak (1990), and Cook (1996) were consulted. The species were cross-checked for synonyms and other taxonomic details through appropriate sources such as the Germplasm Resource Information Network (GRIN -http://www.ars-grin.gov/) and the Integrated Taxonomic Information System (ITIS -http://www.itis.gov/).

After getting useful insights into the diversity and distribution of alien plant species from the literature, thorough field surveys were undertaken over 5 years (2006 - 2011), in different aquatic ecosystems of the Kashmir Himalaya. During the survey presence/absence data together with frequency and cover percentage were recorded to determine the current stages of invasion. Survey specifically focussed on seven lakes (Anchar, Ahansar, Dal, Manasabal, Narangbagh, Nilnag, Waskar & Wular), four wetlands (Hokersar, Malangpora, Tulmula, Kranchu), two rivers (Jehlum & Sindh) and many other permanent or temporary aquatic habitats (see Table 1). For the present study, all those species that have been intentionally or unintentionally introduced, and have spread to areas outside of their natural range were considered alien (Williamson & Fitter 1996). The conspectus included all the alien plant species that were effectively naturalized in aquatic habitats of the region, irrespective of their mode and purpose of introduction and stage of invasion. Species found adjacent to aquatic environments, and which tend to be waterlogged or submerged for at least part of the year, were also considered in this account. We deliberately include the common names of species in the present list for the convenient use of local inhabitants, biodiversity managers and other related agencies.

Geographic affiliations and nativity of the species was established through all possible sources, both published and unpublished, such as *Atlas Florae Europaeae* (Jalas *et al.* 1972 - 2004), *Flora Europaea* (Tutin *et al.* 1968 - 2001), *Index Kewensis Plantarum Phanerogamarum* (Anonymous 1883-1970), Weber (2003), Khuroo *et al.* (2007). In addition, some relevant web sources of the Germplasm Resource Information Network (GRIN -http://www.ars-grin.gov/), the United States Department of Agriculture (USDA - http://plants.usda.gov/), and the Integrated Taxonomic Information System (ITIS -http://www.itis.gov/) were also used. Though nativity was recognized on the basis of phytogeographical distribution of the species, the data are presented at continental scale for the sake of convenience following Pysek *et al.* (2002).

### *Invasion status*

For current invasion status, the species were categorized into different stages of invasion on the

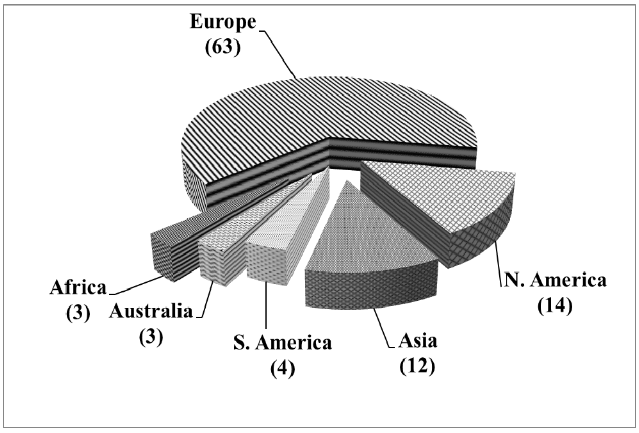


**Fig. 2.** Contribution of various source regions to the Kashmir Himalayan aquatic alien flora. Figures in parentheses represent percentage of species native to each continental region.

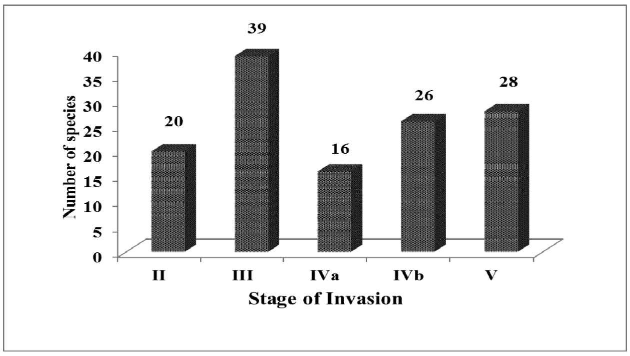


**Fig. 3**. Proportion of aquatic plant species in different stages of invasion in Kashmir Himalaya. Stages denote species at the earliest phase of introduction (II), localized and numerically rare species (III), widespread but rare species (IVa), localized but dominant species (IVb), and widespread and dominant species (V).

basis of the extent of spatial spread in the Kashmir Himalayan region, measured in terms of the frequency percentage across sites using standard quadrat sizes of 0.5, 1 and 5 $m^2$ for free floating, submerged and emergent macrophytes, respectively, in the framework of the CM model. We categorized the documented aquatic macrophytes into four growth forms including emergents, rooted floating-leaf types, free floating types and submersed types, adaptable to diverse habitat conditions, depending upon the level and availability of water throughout the growing seasons. Growth form classification was important for the choice of quadrat size. For instance, counting the number of individuals of free floating species such as *Lemna minor* and *Azolla cristata*, in a large size quadrat (1 or 5 $m^2$) was highly time consuming due to extremely large numbers of individuals in the mats. The final results were normalized to a per $m^2$ area after appropriate conversion.

The CM model described different stages of invasion, starting from resident species in a potential donor region (stage 0), carried through different transport vectors (stage I) and released into the introduced region (stage II). The model divided the stages III through V, based on abundance and distribution of exotic species in the introduced range, depending upon whether the species is localized and numerically rare (stage III), widespread but rare (stage IVa), localized but dominant (stage IVb) or widespread and dominant (stage V). The transitory stages 0 and I were deliberately excluded in the present study because it was practically not feasible to work with alien species at these two stages of invasion. We used subjective scales of frequency and cover percentage provided by Raunkiaer (1934) and Braun-Blanquet (1932), with slight modifications in the latter case, for attributing invasion status to macrophytic species (Table 2).

**Table 2.** Scales of frequency and cover percentage (Braun-Blanquet 1932; *sensu* Raunkiaer 1934), with slight modifications in the latter case, applied for attributing invasion status to macrophytic species.

| Frequency % | Frequency Class | Cover % | Cover Group | Invasion Stage |
|---|---|---|---|---|
| 0 - 20 | A | < 5 | 1 | II |
| 21 - 40 | B | 6 - 25 | 2 | III |
| 41 - 60 | C | 26 - 50 | 3 | IVa |
| 61 - 80 | D | 51 - 75 | 4 | IVb |
| 81- 100 | E | > 75 | 5 | V |

## Results

### *Species conspectus*

Alien aquatic species from typical Kashmir Himalayan water bodies comprised 129 species belonging to 68 genera and 42 families (Appendix Table 1). Cyperaceae and Potamogetonaceae with 22 and 10 species, respectively, were the largest families. Polygonaceae and Lemnaceae with 8 and 7 species, respectively, were the next largest families, followed by Brassicaceae and Labiatae with 6 species each. Poaceae and Nymphaeaceae were represented by 5 species each, and 4 species belonged each to Juncaceae, Lythraceae, and

Ranunculaceae. In addition, the inventory also includes 21 monogeneric families each represented by a single species. The number of species in different genera showed evident variation with *Potamogeton* and *Cyperus*, having 10 species each, as the largest two genera.

### *Species nativity and growth form distribution*

Nativity of the documented alien species (Fig. 2) revealed that the greatest majority were contributed from Europe, followed by North America, and Asia. Only a small proportion of species were natives of South America, Australia and Africa. Classification of species into four growth forms yielded emergents as the dominant group, represented by 87 species (69 %), followed by rooted-floating leaf types with 17 (13 %) species, submersed types with 13 (10 %), and free-floating leaf types with 10 (8 %) species, respectively. Whilst the emergent alien macrophytic species fringed the littoral regions of lakes and wetlands, the rooted-floating leaf types dominated relatively shallower waters. The submersed types were concentrated more in rather deeper waters. The distribution of free-floating type of macrophytes was mainly determined by hydrological fluctuations and direction of water flow. These types of invasive species characteristically formed thick mats, especially in eutrophic aquatic systems.

### *Invasion status and distribution pattern*

Stage-based characterization of the investigated species (Fig. 3, Table 2) revealed 15.5 % species at Stage II (species at earlier stage of introduction), 30.2 % species at Stage III (species that have become localized but are numerically rare), 12.4 % species at Stage IVa (widespread but rare species), 20.1 % species at Stage IVb (localized but dominant species), and 21.7 % species at Stage V (widespread and dominant species). More than 15 water bodies surveyed in the present study included eight lakes, four wetlands, two rivers and many other permanent or temporary aquatic habitats. The distribution pattern of alien plants amongst these water bodies showed clear variation (Fig. 4). The eutrophic standing water bodies, such as lakes Dal and Wular, harboured maximum number of alien species in contrast to running water bodies such as rivers with minimum number of these species. Amongst wetlands the Hokersar, a suburban water body, supported maximum number of alien plant species (Fig. 4). About 50 species were reported from other temporary aquatic habitats and were collectively put under the miscellaneous category.

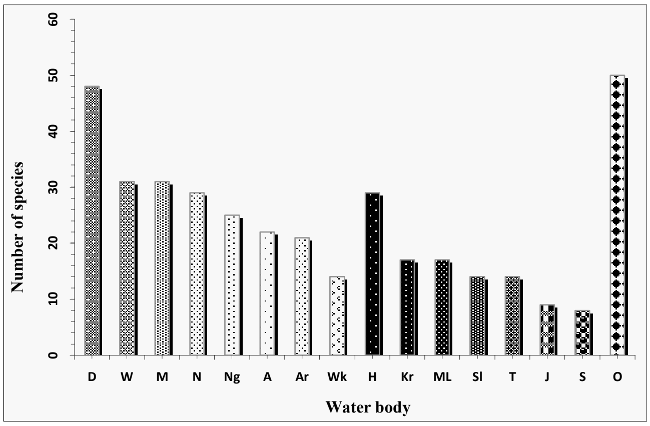


**Fig. 4.** Distribution pattern of alien plant species in different aquatic ecosystems of Kashmir Himalaya. Lakes (A- Ahansar, Ar- Anchar, D- Dal, Ms- Manasbal, Ng- Narangbagh, N- Nilnag, Wk- Waksar, W-Wular); Wetlands (H- Hokersar, Ml- Malangpora, Kr-Kranchu, T- Tulmula, Sl- Shallabugh); and Rivers (J-Jehlum, S-Sindh) and others (O).

## Discussion

About half of the documented 129 alien aquatic species belong to a few families such as Cyperaceae, Potamogetonaceae, Polygonaceae and Lemnaceae. The catalogued alien aquatic species comprise about 40 % of the total aquatic flora of the region, which is relatively more than the proportion of aliens (29 %) in the terrestrial Kashmir Himalayan flora (Khuroo *et al.* 2007). Higher proportion and more preponderance of invasive species in aquatic habitats, especially wetlands (swamps & marshes) occurring in the floodplains of rivers Jehlum and Sindh, can be related to rapid dispersal of propagules by flowing river waters, well known corridors of invasive species spread (Lavoie *et al.* 2003). Distribution of alien species in different aquatic ecosystems in the present study (Fig. 4) seems to be linked to their trophic status, as reflected by the order of species occurrence (eutrophic > mesotrophic > oligotrophic) in different waterbodies (Table 1). There has been a decline in species like *Nelumbo nucifera* in some water bodies such as Hokersar wetland over the years and an almost total extirpation of some economically important and traditionally valued plant species such as *Euryale ferox* has been reported from the region (Khan *et al.* 2004). Such a shift in macrophytic community structure seems associated with the fast spread of invasive species exacerbated by other growing anthropogenic pressures.

The stage-based categorization of the documented species in accordance with the CM model is highly useful to biodiversity managers for management prioritization of alien species and adoption of appropriate management strategies. The characterization of alien species at different stages of invasion (Fig. 3), which actually is reflective of the spatial spread and regional abundance of species, is critical because species at earlier stages of invasion are far easier to manage than species that have already become abundant and widespread. While early detection and predictive modelling approaches hold significance for early stage invaders, eradication, biological control, and other management strategies are more appropriate for Stage V invasive species. The applicability of the CM model for its operational flexibility has been demonstrated for the terrestrial alien flora of the Kashmir Himalayan region (Khuroo *et al.* 2008). In a broader implication, however, a more recent study correlated the species at Stages II and V with their native range size and suggested that a wider native range is a good predictor of plant invasiveness, hence could be used as a simple and low-cost early warning tool in predicting potential invasive species (Shah *et al.* 2011). Similar analysis could be done with the present conspectus of aquatic alien species to further test the models proposed by Shah *et al.* (2011) and Lavoie *et al.* (2012). While our results also point towards usefulness of the CM model for characterization of alien species, highly sophisticated models could be developed for prediction and management of invasions, if other confounding factors (residence time, climate tolerance, phylogeny, native range size) were taken into account.

Contribution of different geographical regions in terms of source of alien plant species to the valley (Fig. 2) revealed an outstandingly higher proportion from Europe than from other continents. This can be partly attributed to similar climatic regimes of the donor and recipient regions, besides the European colonial past of this part of the world that could have facilitated propagule transport from Europe to this region in the late nineteenth and early twentieth centuries. Introduction of alien species from different parts of Asia, especially Siberia and Central Asia, could be due to heavy annual migratory bird influx to various water bodies of Kashmir from these regions, in addition to the relatively short distances that alien species from these neighbouring regions need to cover to reach the valley. Migratory birds can significantly contribute to propagule influx by transporting seeds or other propagules of alien plant species clasped to their feet or feathers across geographical or political barriers (Gosper *et al.* 2005). For aquatic plants the geographical distance between the source of invasive species and the invaded site represents a significant barrier because these species usually cannot survive the time of transport in absence of water (Ashton & Mitchell 1989). Thus, the lowest contributions from Africa and Australia may be attributed to relatively longer distances of these regions from Kashmir Himalaya.

Predominance of emergents amongst various life-form groups of alien species can be attributed to decreasing depth of water bodies due to sediment accumulation (Khan & Shah 2004), because they prefer to grow in shallow waters characterized by seasonal water-level fluctuations and thrive well under semi-aquatic conditions. Emergent species also possess other important attributes that can potentially contribute to their invasiveness, such as tall and rigid stems with broader leaves that shade out nearby competing species, long lived and resistant rhizomes that facilitate overcoming unfavourable conditions, high propagule production and long-range dispersal, and variable vegetative propagation patterns that facilitate colonization of new sites (Ashton & Mitchell 1989). Since submerged species need suitable substratum and sufficient light penetration into the water column for proper growth, their comparatively lower proportion in the present inventory is reflective of absence of such conditions due to growing sediment loading of aquatic ecosystems (Khan & Shah 2004; Khan *et al.* 2004). While free-floating types could be potentially widely spread through moving water currents, their spread is checked by frequent water-level fluctuations and repeated dry periods in most of the water bodies over the years.

In conclusion, the present conspectus of the aquatic alien flora bridges an apparent knowledge gap in the global invasive species list from this region. The database can potentially act as a corner stone for subsequent research on other vital aspects of aquatic invasions in the Kashmir Himalaya, a part of the world where invasive plants often take a back seat to other priorities. The stage-based characterization of the alien flora will help biodiversity and landscape managers in prioritisation of species for appropriate management strategies, besides facilitating the efficient allocation of financial resources for the purpose. The study also takes the CM model a step further from its scientific infancy for practical applications with broader implications for future discourses.

## Acknowledgements

We acknowledge the facilities provided by the Department of Botany, University of Kashmir, Srinagar, J & K, India, to carry out this work. Critical review by three anonymous reviewers on the earlier draft of the manuscript significantly helped improving its quality. Financial support by the University Grants Commission (UGC), New Delhi, through its major project No. 41-425/2012 (SR) to first author is duly acknowledged.

## References

Anonymous. 1883-1970. *Index Kewensis Plantarum Phanerogamarum Vol. I-II (1883-1885) and 15 Suppl. (1886-1970).* Clarendon Press, Oxford

Ashton, P. J., D. S. Mitchell. 1989. Aquatic plants: patterns and modes of invasion, attributes of invading species and assessment of control programmes. Chapter 6. pp. 111-154. *In*: J. A. Drake, H. A. Mooney, F. de Castri, R. H. Groves, F. J. Kruger, M. Rejmanek & M. Williamson (eds.) *Biological Invasions: a Global Perspective.* John Wiley & Sons, New York.

Braun-Blanquet, J. 1932. *Plant Sociology*. New York.

Catford, J. A., R. Jansson & C. Nilsson. 2008. Reducing redundancy in invasion ecology by integrating hypotheses into a single theoretical framework. *Diversity and Distribution* **15**: 22-40.

Colautti, R. I. & H. I. MacIsaac. 2004. A neutral terminology to define 'invasive' species. *Diversity and Distribution* **10**: 135-141.

Cook, C. D. K. 1996. *Aquatic and Wetland Plants of India: a Reference Book and Identification Manual for the Vascular Plants found in Permanent or Seasonal Fresh Water in the Subcontinent of India's South of the Himalayas*. Oxford University Press, New York.

Drexler, J. Z. & B. L. Bedford. 2002. Pathways of nutrient loading and impacts on plant diversity in a New York peatland. *Wetlands* **22**: 263-281.

Dudgeon, David, Angela H. Arthington, Mark O. Gessner, Zen-Ichiro Kawabata, Duncan J. Knowler, Christian Leveque, Robert J. Naiman, Anne Helene, Prieur Richard, Daris Sobo, Melanie L. J. Stiassny & Caroline A. Sullivan. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological Reviews* **81**: 163-182.

Ehrenfeld, J. G. 2008. Exotic invasive species in urban wetlands: environmental correlates and implications for wetland management. *Journal of Applied Ecology* **45**: 1160-1169.

Elton, C. S. 1958. *The Ecology of Invasions by Animals and Plants*. Methuen, London.

Gosper, C. R., D. C. Stansbury & G. Vivian-Smith. 2005. Seed dispersal of fleshy-fruited invasive plants by birds: contributing factors and management options. *Diversity and Distribution* **11**: 549-558.

Hiremath, A. J. & M. Agrawal. 2010. Plant invasion and environmental pollution: causes of concern. *Tropical Ecology* **51**: 303-304.

Hooker, J. D. 1872-1897. *The Flora of British India*. Vols. 1-7. L. Reeve & Co., London.

Jalas, J., J. Suominen, R. Lampinen, A. Kurtto, L. Junikka, S. E. Fröhner, H. E. Weber & A. N. Sennikov (eds.). 1972-2004. *Atlas Florae Europaeae. Distribution of Vascular Plants in Europe.* Vol. 1-14. Helsinki, Finland: Committee for Mapping the Flora of Europe and Societas Biologica Fennica Vanamo.

Kak, A. M. & G. N. Javeid. 1976. *Galium palustre* L. and *Eleocharis acicularis* Roem et Schult. two new plant records for India. *Journal of Bombay Natural History Society* **74**: 208-209.

Kak, A. M. 1984. Family Alismataceae in north Northwestern Himalaya. *Journal of Bombay Natural History Society* **81**: 506-508.

Kak, A. M. 1990. Aquatic and wetland vegetation of Kashmir Himalaya. *Journal of Economic Taxonomic Botany* **14**: 1-14.

Kaul, V., D. P. Zutshi, K. K. Vass. 1973. Aquatic weeds in Kashmir. pp. 79-94. *In*: C. K. Varshney & J. Rzoska (eds.) *Aquatic Weeds in S. E. Asia*. W. Junk, The Hague.

Kaul, M. K. 1986. *Weed Flora of Kashmir Valley*. Scientific Publishers, Jodhpur, India.

Khan, M. A., M. A. Shah., S. S. Mir & S. Bashir. 2004. The environmental status of a Kashmir Himalayan wetland game reserve: Aquatic plant communities and eco-restoration measures. *Lakes & Reservoirs: Research & Management* **9**: 125-132.

Khan, M. A. & M. A. Shah. 2004. Hydrology and sediment loading of Hokersar wetland sanctuary in the Kashmir Himalaya, India. *The Indian Forester* **130**: 899-910.

Khuroo, A. A., I. Rashid, Z. Reshi, G. H. Dar & B. A. Wafai. 2007. The alien flora of Kashmir Himalaya. *Biological Invasions* **9**: 269-292.

Khuroo, A. A., Z. Reshi, I. Rashid, G. H. Dar & Z. S. Khan. 2008. Operational characterization of alien invasive flora and its management implications. *Biodiversity Conservation* **17**: 3181-3194.

Koul, K. & A. R. Naqshi. 1988. Nymphaeaceae of Jammu and Kashmir. *Journal of Bombay Natural History Society* **85**: 454-455.

Kundangar, M. R. D. & D. P. Zutshi. 1987. Ecology and production of some important macrophytes species in two rural communities of Kashmir. *Journal of Hydrobiology* **3**: 57-62.

Lavoie, C., J. Martin, D. Fanny & L. Guy. 2003. Exotic plant species of the St. Lawrence River wetlands: a spatial and historical analysis. *Journal of Biogeography* **30**: 537-549.

Lavoie, C., M. A. Shah, A. Bergeron & P. Villeneuve. 2012. Explaining invasiveness from the extent of native range: new insights from plant atlases and herbarium specimens. *Diversity and Distribution.* DOI: 10.1111/ddi.12014.

Lawes, R. A., H. T. Murphy & A. C. Grice. 2006. Comparing agglomerative clustering and three weed classification frameworks to assess the invasiveness of alien species across spatial scales. *Diversity and Distribution* **12**: 633-644.

Naqshi, A. R. 1981. *Alternanthera caracasana* Kunth. (Amaranthaceae) from Indian subcontinent. *Journal of Economic Taxonomic Botany* **2**: 249-250.

Olden, J. D., J. M. McCarthy, J. T. Maxted, W. W. Fetzer & J. M. Vander Zanen. 2006. The rapid spread of rusty crayfish (*Orconectus rusticus*) with observations on native crayfish declines in Wisconsin (U.S.A.) over the past 130 years. *Biological Invasions* **8**: 1621-1628.

Perbiche-Neves, G., M. S. Júnior, J. L. Portinho, E. M. Shimabukuro, A. R. Ghidini & L. de Brito. 2012. Effect of atypical rainfall on lotic zooplankton: Comparing downstream of reservoir and tributaries with free stretches. *Tropical Ecology* **53:** 149-162.

Pimentel, D., R. Zuniga & D. Morrison. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics* **52**: 273-288.

Pradhan, P., S. S. Mishra, S. K. Chakraborty & R. K. Bhakat. 2005. Diversity of freshwater macrophytic vegetation of six rivers of south West Bengal. *Tropical Ecology* **46**: 193-202.

Prasad, S. N., T. V. Ramachandra, N. Ahalya., T. Sengupta, Alok Kumar, A. K. Tiwari, V. S. Vijayan & Lalitha Vijayan. 2002. Conservation of wetlands of India - a review. *Tropical Ecology* **43**: 173-186.

Pyšek, P., J. Sadlo & B. Mandek. 2002. Catalogue of alien plants of the Czech Republic. *Preslia Praha* **74**: 97-186.

Raunkiaer, C. 1934. *The Life Forms of Plants and Statistical Plant Geography*. Clarendon Press, Oxford.

Reshi, Z., M. A. Shah, I. Rashid & A. A. Khuroo. 2008. Alien plant invasions: Threat to wetland health and public wealth. *Sarovar Saurabh* (ENVIS) **4**: 2-5.

Reshi, Z. 1984. *Ecology and Taxonomy of Weeds of District Anantnag, Kashmir Himalaya.* M. Phil. Dissertation, Department of Botany, University of Kashmir, Srinagar, J. & K. India.

Richardson, D. M., P. Pyšek, M. Rejmanek, M. G. Barbour, F. D. Panetta & C. J. West. 2000. Naturalization and invasion of alien plants: concepts and definitions. *Diversity Distribution* **6**: 93-107.

Shah, M. A., Z. Reshi & C. Lavoie. 2011. Predicting plant invasiveness from native range size: clues from Kashmir Himalaya. *Journal of Plant Ecology*. DOI: 10.1093/jpe/RTR021

Shah, M. A. & Z. A. Reshi. 2012. Invasion by alien macrophytes in freshwater ecosystems of India. pp. 199-215. *In*: J. R. Bhatt, J. S. Singh, S. P. Singh, R. S. Tripathi & R. K. Kohli (eds.) *Invasive Alien Plants: An Ecological Appraisal for the Indian Subcontinent.* CAB International.

Stewart, R. R. 1972. An annotated catalogue of the vascular plants of west Pakistan and Kashmir. Fakhri Press, Karachi, Pakistan.

Tutin, T. G., V. H. Heywood, N. A. Burges, D. H. Valentine, S. M. Walters & D. A. Webb. 1968-2001. *Flora Europaeae* Vol. I-V, Cambridge, United Kingdom: Cambridge University Press.

Weber, E. 2003. *Invasive Plant Species of the World: a Reference Guide to Environmental Weeds*. CABI Publishing, UK.

Williamson, M. & A. Fitter. 1996. The varying success of invaders. *Ecology* **77**: 1661-1666.

Zedler, J. B. & S. M. Kercher. 2004. Causes and consequences of invasive plants in wetlands: opportunities, opportunists and outcomes. *Critical Reviews in Plant Sciences* **23**: 431-452.

Zutshi, D. P. 1975. Association of macrophytic vegetation in Kashmir lakes. *Vegetatio* **30**: 61-70.

(Received on 10.03.2012 and accepted after revisions, on 07.12.2012)

**Appendix Table 1.** Check-list of aquatic alien plant species found in the Kashmir Himalayan freshwater ecosystems together with their common name, growth form, nativity and extent of occurrence in native and non-native regions.

| Family/plant species | Common name | Growth form* | Origin* | No. of water bodies of occurrence | Invasion stage |
|---|---|---|---|---|---|
| Alismataceae | | | | | |
| *Alisma gramineum* Lej. | Narrowleaf waterplantain | E | Eu | 3 | III |
| *Alisma lanceolatum* With. | Lanceleaf water plantain | E | Eu | 2 | III |
| *Alisma plantago-aquatica* L. | Mad dog weed | E | Eu | 8 | V |
| *Saggitaria latifolia* Willd. | Broadleaf arrowhead | E | NAm | 2 | III |
| *Saggitaria sagittifolia* L. | Arrowhead | E | Eu | 10 | V |
| Amaranthaceae | | | | | |
| *Amaranthus lividus* L. | Amaranth | E | As, Af, SAm | 1 | II |
| *Alternanthera sessilis* (L.) R. Br. ex DC. | Sessile alligatorweed | E | SAm | 2 | IVb |
| *Alternanthera caracasana* Kuwth. | Washerwoman | E | SAm, NAm | 2 | III |
| Apiaceae | | | | | |
| *Berula erecta* (Huds.) Coville | Water-parsnip | E | Eu | 5 | III |
| Araceae | | | | | |
| *Acorus calamus* L. | Sweet flag | E | As | 3 | II |
| Asteraceae | | | | | |
| *Bidens cirnua* L. | Marsh Beggarticks | E | NAm | 1 | IVa |
| *Bidens tripartita* L. | Burr-marigold | E | Eu | 5 | II |
| Azollaceae | | | | | |
| *Azolla cristata* Kaulf. | Water Fern | FF | NAm | 4 | III |
| Boraginaceae | | | | | |
| *Myosotis caespitosa* Schultz | Forget-me-not | E | NAm | 1 | III |
| *Myosotis scorpioides* L. | Water Forget-Me-Not | E | Eu | 3 | IVb |
| Brassicaceae | | | | | |
| *Barbarea intermedia* Boreau | Winter cress | E | Eu | 1 | III |
| *Barbarea vulgaris* W. T. Aiton | Yellow rocket | E | Eu | 3 | IVa |
| *Cardamine flexuosa* With. | Woodland bittercress | E | Eu | 1 | IVb |
| *Cardamine hirsuta* L. | Hairy bittercress | E | Eu | 5 | IVb |
| *Nasturtium officinale* W. T. Aiton | Watercress | E | Eu | 5 | IVb |
| *Rorippa islandica (Oeder)* Borbás | Marsh cress | E | Eu | 2 | IVb |
| Butomaceae | | | | | |
| *Butomus umbellatus* L. | Flowering rush | E | Eu | 4 | V |
| Callitrichaceae | | | | | |
| *Callitriche stagnalis* Scop. | Pond water-starwart | E | Eu | 3 | IVb |
| Caryophyllaceae | | | | | |
| *Myosoton aquaticum* (L.) Moench | Giantchickweed | E | Eu | 3 | III |
| *Sagina saginoides* (L.) H.Karst. | Pearlwort | E | Eu | 2 | IVb |
| Ceratophyllaceae | | | | | |
| *Ceratophyllum demersum* L. | Coontail | S | Eu | 10 | V |
| Cyperaceae | | | | | |
| *Carex diandra* Schrank | Lesser panicled sedge | E | NAm | 1 | II |
| *Carex diluta* Bieb. | Alpine nerved sedge | E | Eu | 1 | IVa |
| *Cladium mariscus* (L.) Pohl | Saw-grass | E | Eu | 1 | III |

Contd...

**Appendix Table 1.** Continued.

| Family/plant species | Common name | Growth form* | Origin* | No. of water bodies of occurrence | Invasion stage |
|---|---|---|---|---|---|
| *Cyperus difformis* L. | Smallflower variable flat sedge | E | Eu | 5 | V |
| *Cyperus alternifolius* L. | Flat sedge | E | Af | 2 | IVa |
| *Cyperus fuscus* L. | Brown flatsedge | E | Eu | 6 | IVb |
| *Cyperus globosus* All. (Syn. *Pycreus flavidus* (Retz.) T. Koyama) | Yellow flat-sedge | E | Af, Eu | 8 | V |
| *Cyperus glomeratus* L. | Round headed nutsedge | E | Eu | 9 | V |
| *Cyperus iria* L. | Rice flatsedge | E | As, Af | 1 | IVb |
| *Cyperus michelianus* (L.) Link | Zigolo del micheli | E | Eu | 3 | III |
| *Cyperus pumilus* L. | Low flatsedge | E | Au | 1 | IVa |
| *Cyperus rotundus* L. | Nutsedge | E | Eu | 10 | V |
| *Cyperus sanguinolentus* L. | Purpleglume flatsedge | E | NAm,S Am | 1 | III |
| *Eleocharis atropurpurea* (Retz.) Kunth | Purple spikerush | E | SAm | 1 | III |
| *Eleocharis acicularis* (L.) Roem. & Schult. | Least spikerush | E | NAm,S Am | 1 | III |
| *Eleocharis palustris* (L.) Roem. & Schult. | Red-stalked spikerush | E | Eu | 7 | III |
| *Eleocharis parishii* Britton | Parish's spike rush | E | Nam | 2 | II |
| *Eleocharis pauciflora* Link | Few-flowered spike rush | E | N.Am | 1 | II |
| *Fimbristylis dichotoma* (L.) Vahl. | Fringe-rush | E | Af, As | 1 | IVb |
| *Scirpus juncoides* Roxb. | Weakstalk bulrush | E | NAm | 1 | II |
| *Scirpus martimus* L. | Prairie bulrush | E | Eu | 6 | II |
| *Scirpus triqueter* L. | Triangular Club-rush | E | Eu | 4 | IVa |
| Elatinaceae | | | | | |
| *Elatine triandra* Schkuhr | Three-stamened waterwort | S | Eu | 2 | IVa |
| Eriocaulaceae | | | | | |
| *Eriocaulon sieboldianum* Siebold & Zucc. ex Steud. | Hatpins | E | NAm | 2 | II |
| Haloragaceae | | | | | |
| *Myriophyllum verticillatum* L. | Whorled water milfoil | S | Eu | 13 | IVb |
| *Myriophyllum spicatum* L. | Eurasian Watermilfoil | S | Eu | 13 | V |
| *Myriophyllum aquaticum* (Vell.) Verdc. | Parrotfeather | S | SAm | 10 | V |
| *Hippuris vulgaris* L. | Mare's tail | E | Eu | 5 | IVa |
| Hydrocharitaceae | | | | | |
| *Hydrilla verticillata* (L.f.) Royle | Hydrilla | S | Eu | 9 | V |
| *Hydrocharis dubia* (Blume) Backer | European frog-bit | E | As | 2 | IVb |
| *Vallisneria spiralis* L. | Tape grass | FF | Eu | 3 | III |
| Juncaceae | | | | | |
| *Juncus articulatus* L. | Jointed rush | E | Eu | 9 | V |
| *Juncus bufonius* L. | Toad rush | E | Eu | 8 | IVb |
| *Juncus effusus* L. | Soft rush | E | Eu | 6 | IVb |
| *Juncus inflexus* L. | Hard rush | E | Eu | 3 | II |
| Juncaginaceae | | | | | |
| *Triglochin palustris* L. | Marsh arrow grass | E | Eu | 4 | III |

Contd...

**Appendix Table 1.** Continued.

| Family/plant species | Common name | Growth form* | Origin* | No. of water bodies of occurrence | Invasion stage |
|---|---|---|---|---|---|
| Labiatae (Lamiaceae) | | | | | |
| *Mentha aquatica* L. | Water mint | E | Eu | 5 | III |
| *Mentha arvensis* L. | Corn mint | E | Eu | 1 | III |
| *Mentha longifolia* (L.) Huds. | Horsemint | E | Eu | 9 | V |
| *Mentha* × *piperita* L. | Whitepepper mint | E | Eu | 1 | IVa |
| *Mentha spicata* L. | Spearmint | E | NAm | 1 | II |
| *Lycopus europaeus* L. | Gypsywort | E | Eu | 1 | IVa |
| Lemnaceae | | | | | |
| *Lemna gibba* L. | Large duckweed | FF | Eu | 5 | IVa |
| *Lemna minor* L. | Small duckweed | FF | Eu | 8 | V |
| *Lemna turionifera* Landolt | Turion duckweed | FF | NAm | 1 | II |
| *Lemna trisulca* L. | Star duckweed | FF | Eu | 5 | II |
| *Spirodela polyrhiza* (L.) Schleid. | Great duckweed | FF | Eu | 7 | V |
| *Wolffia arrhiza* (L.) Horkel ex Wimm. | Least duckweed | FF | Eu | 2 | III |
| *Wolffia columbiana* H. Karst. | Water meal | FF | NAm | 1 | II |
| Lentibulariaceae | | | | | |
| *Utricularia aurea* Lour. | Bladderwort | S | As, Au | 3 | III |
| Lythraceae | | | | | |
| *Ammania auriculata* Willd. | Eared redstem | E | As, Au | 1 | III |
| *Ammania baccifera* L. | Monarch redstem | E | As | 1 | III |
| *Lythrum salicaria* L. | Purple loosestrife | E | Eu | 6 | IVa |
| *Rotala densiflora* (Willd.) Koehne | Roudleaf rotala | E | As, Au | 1 | IVb |
| Marsiliaceae | | | | | |
| *Marsilia quadrifolia* L. | European waterclover | RF | Eu | 11 | V |
| Menyanthaceae | | | | | |
| *Menyanthes trifoliata* L. | Bogbean | E | Eu | 6 | III |
| *Nymphoides peltata* (S.G.Gmel.) Kuntze | Yellow floating heart | RF | Eu | 11 | V |
| Najadaceae | | | | | |
| *Najas marina* L. | Spiny naiad | S | Eu | 3 | IVa |
| Nelumbonaceae | | | | | |
| *Nelumbo nucifera* Gaertn. | Sacred water lotus | RF | As, Eu | 8 | V |
| Nymphaeceae | | | | | |
| *Nymphaea alba* L. | White water lily | RF | Eu | 8 | IVb |
| *Nymphaea lotus* L. | White lotus | RF | Eu | 1 | II |
| *Nymphaea mexicana* Zucc. | Yellow waterlily | RF | NAm | 2 | III |
| *Nymphaea tetragona* Georgi. | Pigmy water lily | RF | Eu | 2 | III |
| *Nymphaea tuberosa* Paine. | Tuberous water lily | RF | NAm | 1 | III- |
| Onagraceae | | | | | |
| *Epilobium hirsutum* (L) Gray | Codlins cream | E | Eu | 7 | V |
| *Epilobium palustre* L. | Marsh willow herb | E | Eu | 3 | IVa |
| Orchidaceae | | | | | |
| *Spiranthes lancea* (Thunb.) Baker | Lady's tress | E | Eu | 1 | II |
| Poaceae | | | | | |
| *Echinochloa colonum* (L.) Link. | Jungle rice | E | As | 1 | III |
| *Echinochloa crus-galli* (L.) P.Beauv. | Barnyard millet | E | Eu | 3 | IVa |

Contd...

**Appendix Table 1.** Continued.

| Family/plant species | Common name | Growth form* | Origin* | No. of water bodies of occurrence | Invasion stage |
|---|---|---|---|---|---|
| *Paspalum paspalodes* (Michx.) Scribn. | Paspalum | E | Sam | 1 | III |
| *Phalaris arundinacea* L. | Reed canarygrass | E | Eu | 5 | IVb |
| *Phragmites australis* (Cav.) Trin. ex Steud. | Common reed | E | Eu | 9 | V |
| Polygonaceae | | | | | |
| *Polygonum hydropiper* L. | Swamp smartweed | RF | Eu | 8 | V |
| *Polygonum amphibium* L. | Knotweed | E | NAm | 6 | V |
| *Polygonum nepalense* Meisn. | Nepal persicaria | E | As | 1 | IVa |
| *Rumex aquaticus* L. | Red dock | E | As, Eu | 3 | IVb |
| *Rumex chalepensis* Mill | Wang guo suan mo | E | As | 1 | III |
| *Rumex conglomeratus* Murray | Sharp dock | E | Eu | 6 | II |
| *Rumex dentatus* L. | Aegean dock | E | Eu | 1 | IVb |
| *Rumex paulsenianus* Rech. | Fewleaved dock | E | As | 1 | II |
| Potamogetonaceae | | | | | |
| *Potamogeton crispus* L. | Curly leaf pondweed | S | Eu | 8 | V |
| *Potamogeton filiformis* Pers. | Pondweed | RF | Eu | 7 | IVb |
| *Potamogeton berchtoldii* Fieber | Potamot très ténu | RF | Eu | 3 | IVb |
| *Potamogeton natans* L. | Broadleaf pondweed | S | Eu | 13 | IVb |
| *Potamogeton nodosus* Poir. | Long leaf pondweed | RF | Eu | 9 | V |
| *Potamogeton lucens* L. | Pondweed | S | Eu | 9 | III |
| *Potamogeton pectinatus* L. | Sago pondweed | RF | Eu | 5 | IVb |
| *Potamogeton perfoliatus* L. | Clasping leaf pondweed | S | Eu | 6 | III |
| *Potamogeton pusillus* L. | Small pondweed | S | Eu | 5 | III |
| *Potamogeton trichoides* Cham. & Schltdl. | Hairlike pondweed | RF | Af | 3 | II |
| Primulaceae | | | | | |
| *Primula inayati* Duthei | Cowlip | E | As | 1 | II |
| Ranunculaceae | | | | | |
| *Caltha alba* K. Jacq | Marsh marigold | E | Eu | 1 | II |
| *Rananculus aquatilis* L. | Water crowfoot | RF | Eu | 2 | IVb |
| *Rananculus lingua* L. | Greater spearwort | RF | Eu | 8 | III |
| Salviniaceae | | | | | |
| *Salvinia natans* All. | Water fern | FF | Eu | 8 | V |
| Scrophulariaceae | | | | | |
| *Veronica beccabunga* L. | European speedwell | E | Eu | 8 | III |
| Sparginaceae | | | | | |
| *Sparganium erectum* Huds | Bur reed | E | Eu | 9 | V |
| Trapaceae | | | | | |
| *Trapa natans* L. | Water chestnut | RF | Eu | 8 | V |

Contd...

**Appendix Table 1.** Continued.

| Family/plant species | Common name | Growth form* | Origin* | No. of water bodies of occurrence | Invasion stage |
|---|---|---|---|---|---|
| Typhaceae | | | | | |
| *Typha angustata* Bory & Chaub. | Southern cattail | E | Eu, NAm | 10 | V |
| *Typha laxmannii* Lepech. | Narrow-leaved european cattail | E | EuAs, | 2 | III |
| *Typha latifolia* L. | Broadleaf cattail | E | NAm | 5 | III |
| Zannichelliaceae | | | | | |
| *Zannichellia palustris* L. | Horned podweed | S | Eu | 3 | III |

***Abbreviations**: As- Asia, Au- Australia, Eu- Europe, E- emergent, FF- free floating type, NAm- North America, SAm - South America, S- submersed, RF- rooted-floating leaf type.