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RESEARCH ARTICLE

Introduction Pathways of Invasive Alien Plants in the Lake Cluster of Pokhara Valley, Nepal

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ABSTRACT
The Lake Cluster of the Pokhara Valley (LCPV), a Ramsar site, has been invaded by several invasive alien plant species (IAPS), yet the introduction pathways of these species remain unknown. In this paper, the possible introduction pathways and invasion history of five wetland IAPS of the LCPV have been identified and reported for analysis. Direct field observations were combined with data obtained from the questionnaire survey with the local residents to identify introduction pathways and invasion history. Among five invasive alien plants, *Pontederia crassipes* and *Pistia stratiotes* were introduced as ornamental plants that escaped to wetlands and established their populations during 1980s and 1990s respectively. Similarly, *Ipomoea carnea* subsp *fistulosa* was introduced during the 1990s for fencing and soil bioengineering purposes. It is highly likely that *Leersia hexandra* and *Alternanthera philoxeroides* were introduced accidentally as none of the local residents interviewed could explain the purpose of their introduction. The local residents have noticed the occurrence of *L. hexandra* for >50 years while *A. philoxeroides* might have reached to the LCPV sometime between 2015 and 2020. The results suggest the wetland IAPS have been introduced to the LCPV both intentionally as well as accidentally, and that the prioritizing pathway management can prevent their future introductions.
KEYWORDS: Ramsar site, wetlands, ornamental plants, intentional introductions, accidental introductions

INTRODUCTION
Biological invasions are the result of human-mediated extra-range dispersal, which, unlike natural extra-range dispersal, is usually the result of many introductions from the multiple sources to the multiple locations (Wilson et al., 2009). The pace of invasion is affected by the introduction frequency of the propagules of alien species, the availability of suitable areas for their establishment, and population growth rates (Elliott,

2012). The entire process of biological invasion constitutes the four stages: transport, introduction, establishment, and spread (Blackburn et al., 2011). Understanding the extent of the alien plant introduction pathways is critical for species invasions (Pysek et al., 2011). An interception of the potentially invasive species in their way of 'transport' and 'introduction' is the most cost-effective measure for the management of invasive species. For such measures to be implemented at the local level, it is indispensable to identify the introduction pathway of invasive alien species.

Alien species can enter a new location through three basic introduction pathways: the importation of a commodity, the introduction of a transport vector, and/or natural spread from a neighboring region where the species is already alien (Hulme et al., 2008). These three systems provide six major pathways, depending on the level of human involvement: release, escape, contamination, stowaway, corridor, and unaided. A single species may utilize the multiple introduction pathways and vice versa. Similarly, the invasive alien plants are introduced to wetlands both intentionally (e.g. trading item) as well as accidentally (Azan et al., 2015). However, the information pertaining to the introduction pathways of invasive alien plants in most of the wetlands in Nepal including the Lake Cluster of the Pokhara Valley (LCPV) remains unknown. In this context, the present study was conducted with the aim of identifying the introduction pathways of wetland invasive alien plants in the LCPV and tracing back their invasion history. Almost five aquatic invasive alien plant species have been found, which invade the lakes (see Table 1). For their management including preventing them from the further invasion to neighboring freshwater bodies, the knowledge of their dispersal mechanism and invasion history is crucial.

MATERIALS AND METHODS

Pokhara Valley, the capital city of the Gandaki Province is the most visited tourist destination of Nepal. Almost a million tourists visit Pokhara every year (Pathak, 2023). The valley is located between 27.55º to 28.23º N latitude and 83.48º to 84.11º E in longitude within an elevation range of 580-900 m asl (Pathak, 2023). It receives an average rainfall of 3515 mm with a minimum temperature of 7ºC (esp. in January) and a maximum temperature of 31.4ºC (Pathak, 2023). The valley has wet seasons from mid-February to mid-November and dry periods from mid-November to mid-February. Its floor is bestowed with nine lakes of international importance, which are included in the Ramsar site with the name, Lake Cluster of Pokhara Valley (LCPV). Among them, Phewa, Begnas, and Rupa lakes are popular. Most probably with tourist activities, the invasive alien plant species are increasing, spreading, and causing social, economic, and ecological impacts (Pathak et al., 2021).

Three larger lakes: Phewa, Begnas, and Rupa lakes of the LCPV, were the study sites. The authors chose this site for the study because there were the increasing concerns about the detrimental impacts of the invasive alien plant species in the lakes of LCPV and the study of this kind may help the management of these invaders. The interview with the inhabitants with a semi-structured questionnaire was the technique of the primary data collection. The respondents were the stakeholders as well as beneficiaries of these lakes.

Table 1

List of aquatic invasive alien plant species present in each lake (Pathak et al., 2021)

SN	Name of the species	Phewa	Begnas	Rupa
1	*Pontederia crassipes*	√	√	√
2	*Pistia stratiotes*	√	√	√

3	*Ipomoea carnea* subsp. *fistulosa fistulosa*	√	√	√
4	*Alternanthera philoxeroides*	√	×	×
5	*Leersia hexandra*	√	√	√

Direct field observations by the first author were combined with data obtained from the questionnaire survey with the residents to identify the introduction pathways and their invasion history. The boaters, farmers, hoteliers, teachers, political activists, and fishermen (a total 56 persons) were interviewed for data collection. The total percentage was obtained by dividing the number of respondents for the particular response by the total number of respondents, multiplied by 100. The respondents were selected by snowball sampling method (Etikan et al., 2016) from the inhabitants and beneficiaries of three major lakes, i.e., Phewa, Begnas, and Rupa. The remaining six wetlands of the LCPV were excluded since they remained free from the major invasive alien plant species (however, the *Leersia hexandra* may present) at the time of the study. Similarly, the open-ended questionnaires, as well as the photographs of wetland IAPS (Pathak et al., 2021) were used during the interview. Personal interviews were conducted and recorded with the permission of elderly inhabitants of the study sites. The collected data were analyzed to identify the purpose (pathways) of introduction (if any) of a particular IAPS and their first date of introduction on a scale of decades.

RESULTS

Pontederia crassipes was introduced first in Phewa Lake during the early 1980s (see Table 2). It might have been introduced accidentally through the fingerlings or intentionally as an ornamental plant from the cities like Bhairahawa or Chitwan in the southern part of Nepal (see Figure 1). It was brought to Begnas Lake and Rupa Lake in the late 1980s as an ornamental plant. *Pistia stratiotes* was first noticed in Phewa, Begnas, and Rupa during the 1990s and might have been introduced accidentally along with the fingerlings or introduced as an ornamental plant. The propagules of *Pistia stratiotes* might have also originated from Chitwan or Bhairahawa. *Pistia stratiotes* was noticed in these lakes nearly five years later than *Pontederia crassipes*. Similarly, *Ipomoea carnea* subsp. *fistulosa* was introduced to Phewa during the early 1980s and to Begnas during the late 1980s. Likewise, it was brought to Rupa during the 1990s. The introduction pathways and their invasion history of *Alternanthera philoxeroides* were not reported by any respondents but the weed was spotted by the authors in 2019 at a single location in Khahare of Phewa Lake. Given that the weed was confined at a single location with very low abundance, it might have arrived at the location after 2015. Another IAPS *Leersia hexandra* was commonly found in all three wetlands but the respondents could not inform the purpose and time of introduction; they informed that the species was there for >50 years.

Table 2

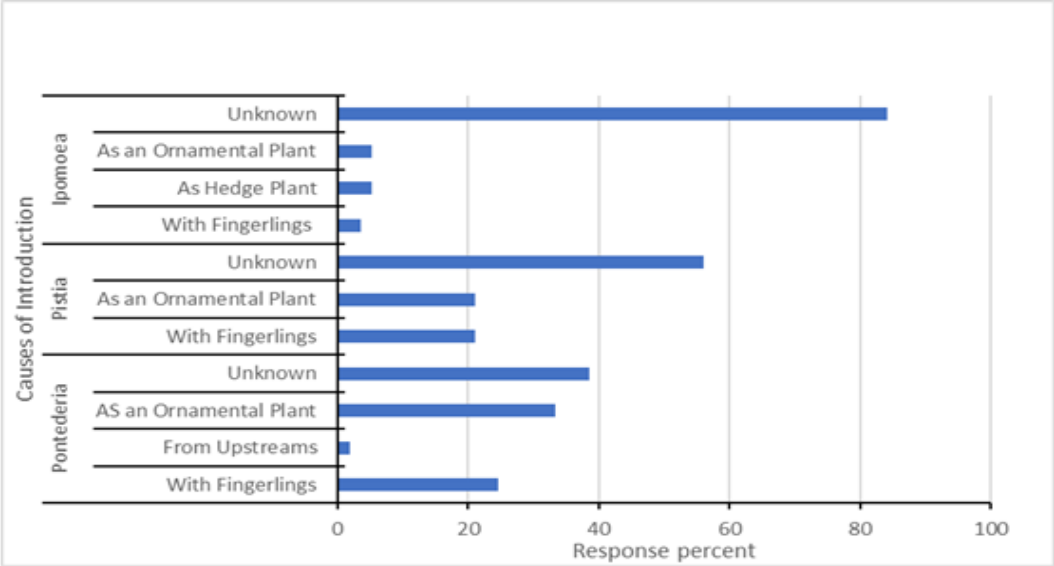
Approximate time of the introduction of IAPS in LCPV

SN	IAPS	Lake	Time in Decade	Respondent (%)
1	*Pontederia crassipes*	Phewa	1980s	80
			1990s	20
		Begnas	1970s	11
			1980s	11
			1990s	53

			2000s	26
		Rupa	1980s	6
			1990s	67
			2000s	26
2	*Pistia stratiotes*	Phewa	1990s	42
			2000s	11
			2010s	16
		Begnas	1970s	11
			2080s	5
			2090s	37
			2000s	37
			2010s	5
			No response	11
		Rupa	1990s	67
			2000s	6
			No response	28
3	*Ipomoea carnea* subsp. *fistulosa*	Phewa	1980s	35
			1990s	20
			2000s	5
			No response	35
		Begnas	1980s	21
			1990s	16
			2000s	5
			No response	58
		Rupa	1970s	6
			1980s	11
			19900s	44
			2000s	22
			No response	17

Figure 1

Pathways of introduction of IAPS to the LCPV



DISCUSSION

Although *Pontederia crassipes*, one of the globally worst invasive species, was introduced in Phewa, Rupa, and Begnas during the 1980s, there is no introduction of these species in the other seven wetlands of the LCPV (Pathak et al., 2021). It is therefore of utmost importance to prevent the introduction of this species to these seven wetlands by making the different stakeholders aware of the introduction pathways and ecological consequences when introduced. The introduction pathway of *P. crassipes* in the present study area was similar to the report of several other previous studies in the different parts of the world. For example, the intentional introduction of *P. crassipes* as fish feed has been reported in western Nepal (Bhatta & Shrestha, 2021). An evidence that fishes feed on *P. crassipes* is also available from a study in Illinois River, USA (VonBank et al., 2014). In the inter-connected wetlands, the hydrological connectivity may also serve as the introduction pathways to the downstream water bodies (May, 2022). The weed was reported to be introduced to Asia at the end of the nineteenth century via Japan and Indonesia (Tellez et al., 2008). In some regions such as Iran, the introduction pathway remains unknown (Zarkami et al., 2021).

Although *Pontederia crassipes*, *Pistia stratiotes*, and *Ipomoea carnea* subsp. *fistulosa* have been introduced both intentionally as well as accidentally, the intentional introduction appears to be more important. For example, *P. crassipes* and *P. stratiotes* are commonly offered in the water garden and aquarium trade in Ontario, Canada (Adebayo et al., 2011). *Ipomoea carnea* subsp. *fistulosa* has been also cultivated extensively for ornamental purposes (Chen et al., 2018) as well as for soil bio-engineering (Pathak et al., 2021a). Once it escapes to the wild, it can be problematic in wetlands. For example, in Koshi Tappu Wild Life Reserve (KTWR) area, a Ramsar site, *Ipomoea carnea* subsp. *fistulosa* is the most problematic along with the *Pontederia crassipes* (Pandey et al., 2020).

When the introduction pathways of three species, for which they are known, are assessed against a framework proposed by Hulme et al., (2008), the introduction pathways of all three species are associated with the importation of commodities. In particular, the introduction pathways of these species can be categorized as 'release' (e.g. *Ipomoea carnea* subsp. *fistulosa* for soil bioengineering), 'escape' (e.g. from ornamental *Pontederia crassipes* and *Pistia stratiotes* to their weedy populations) and 'contaminants' (e.g. *P. crassipes* as a contaminant of fingerlings transportation). Since the purpose of introduction of the remaining two species (*Alternanthera philoxeroides* and *Leersia hexandra*) is currently unknown, it is highly likely that they were also introduced as contaminants. But, further investigations are needed to support this notion.

CONCLUSION

Pontederia crassipes and *Pistia stratiotes* were introduced primarily as ornamental plants, which might have escaped to wetlands and established their populations during the 1980s and 1990s respectively. *Ipomoea carnea* subsp. *fistulosa* was introduced during the 1990s for fencing purposes. It is highly possible that *Leersia hexandra* and *Alternanthera philoxeroides* were introduced accidentally as none of the residents interviewed could explain the purpose of their introduction. Six of the nine wetlands of the LCPV are still free from noxious invasive weeds such as *Pontederia crassipes* and *Pistia stratiotes*. Similarly, *Alternanthera philoxeroides* have been reported only in Phewa Lake. The further expansion of these IAPS into other wetlands can be prevented when the introduction pathways of the IAPS are accounted for in the management of the LCPV. This study is unique to this type in LCPV and will help for more discussions in the further research of this kind.

RECOMMENDATION

It seems that the aquatic invasive alien plant species have been introduced in the recent past. Recognizing the negative impacts on various aspects of life, every year, the mechanical removal of water hyacinths was carried out after 1996 from Phewa Lake. However, the problem appears every year. Therefore, it is recommended for the complete removal from the source and lake shores without leaving any traces of the IAPS. The present study on the dispersal pathways of the IAPS may contribute to their management.

AUTHOR CONTRIBUTIONS

Dr Hom Nath Pathak, data collection, analysis and manuscript writing, Dr Dinesh Raj Bhuju, revision of the MS and Dr Bharat Babu Shrestha, revision of the MS.

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REFERENCES

Adebayo, A. A., Briski, E., Briski, E., Kalaci, O., Hernandez, M., Ghabooli, S., Beric, B., Chan, F.T., Zhan, A., Fifield, E., Leadley, T. & MacIsaac, H. J. (2011). Water hyacinth (Eichhornia crassipes) and water lettuce (Pistia stratiotes) in the Great Lakes: playing with fire? *Aquatic Invasions*, *6*(1), 91-96. https://scholar.uwindsor.ca/biologypub/1166

Azan, S., Bardecki, M., & Laursen, A. E. (2015). Invasive aquatic plants in the aquarium and ornamental pond industries: A risk assessment for southern Ontario (Canada). *Weed Research*, *55*(3), 249-259.

Bhatt, P., & Shrestha, B. B. (2021). Invasive alien plants in wetlands of Kanchanpur District, Western Nepal. *International Journal of Ecology and Environmental Sciences*, *47*(2), 79-89.

Blackburn, T. M., Pyšek, P., Bacher, S., Carlton, J. T., Duncan, R. P., Jarošík, V., ... & Richardson, D. M. (2011). A proposed unified framework for biological invasions. *Trends in Ecology & Evolution*, *26*(7), 333-339.

Chen, L. M., Ho, B. C., Choo, L. M., & Koh, S. L. (2018). Additions to the flora of Singapore, new and overlooked records of naturalized plant species (1). *Nature in Singapore*, *11*, 63-75.

Elliott, E. C., & Cornell, S. J. (2012). Dispersal polymorphism and the speed of biological invasions. *PloS one*, *7*(7), e40496. https://doi.org/10.1371/journal.pone.0040496

Etikan, I., Alkassim, R., & Abubakar, S. (2016). Comparison of snowball sampling and sequential sampling technique. *Biometrics and Biostatistics International Journal*, *3*(1), 55.

Hulme, P. E., Bacher, S., Kenis, M., Klotz, S., Kühn, I., Minchin, D., ... & Vilà, M. (2008). Grasping at the routes of biological invasions: A framework for integrating pathways into policy. *Journal of Applied Ecology*, *45*(2), 403-414.

May, L., Dobel, A. J., & Ongore, C. (2022). Controlling water hyacinth (Eichhornia crassipes (Mart.) Solms): A proposed framework for preventative management. *Inland Waters*, *12*(1), 163-172.

Pandey, P., Shah, D. N., & Tachamo-Shah, R. D. (2020). Impact of invasive alien plant species on aquatic biodiversity of Koshi Tappu wetlands: Ramsar site, Nepal. *Banko Janakari*, *30*(2), 48-58.

Pathak, H. N., Bhuju, D. R., Shrestha, B. B., & Ranjitkar, S. (2021). Impacts of invasive alien plants on ecosystem services of Ramsar lake cluster in middle mountain Nepal. *Global Ecology and Conservation*, *27*, e01597.

Pathak, H. N., Shrestha, B. B., Bhuju, D. R., & Subedi, D. S. (2021). Spatial distribution of invasive alien plants in Pokhara valley, Nepal. *Pak. J. Bot*, *53*(3), 1015-1024.

Pathak, H. N. (2023). *Diversity, distribution, and impacts of invasive alien plant species in lake cluster and associated landscape in Pokhara valley, Central Nepal* (Doctoral dissertation, Institute of Science & Technology, Tribhuvan University, Nepal).

Pyšek, P., Jarošík, V., & Pergl, J. (2011). Alien plants introduced by different pathways differ in invasion success: Unintentional introductions as a threat to natural areas. *PloS One*, *6*(9), e24890.

Shrestha, B. B. (2019). Management of invasive alien plants in Nepal: Current practices and future prospects. *Tropical Ecosystems: Structure, Functions and Challenges in the Face of Global Change*, 45-68.

Téllez, T. R., López, E. M. D. R., Granado, G. L., Pérez, E. A., López, R. M., & Guzmán, J. M. S. (2008). The water hyacinth, Eichhornia crassipes: An invasive plant in the Guadiana River Basin (Spain). *Aquatic Invasions*, *3*(1), 42-53.

VonBank, J. A., Casper, A. P., Hagy, H. M., & Yetter, A. P. (2015). An assessment of aquatic invasive plants in the Illinois River: Water hyacinth surveillance, mapping, persistence, and potential seed dispersal annual progress report period 1 May 2014–30 April 2015.

Wilson, J. R., Dormontt, E. E., Prentis, P. J., Lowe, A. J., & Richardson, D. M. (2009). Something in the way you move: Dispersal pathways affect invasion success. *Trends in Ecology & Evolution*, *24*(3), 136-144.

Zarkami, R., Esfandi, J., & Sadeghi, R. (2021). Modeling occurrence of invasive water hyacinth (Eichhornia crassipes) in wetlands. *Wetlands*, *41*(1), 8.

APPENDIX

List of Respondents in Dispersal Pathways of IAPS in LCPV

SN	Name & age	Lake Territory
1	Man Bdr Thapa, 56 yrs	Begnas
2	Raghunath Tiwari, 77 yrs	Begnas
3	Sujan Jalari, 35 yrs	Begnas
4	Meghanath Tiwari, 61 yrs	Begnas
5	Mrs Shiva Kandel, 60 yrs	Begnas
6	Maya Devi Bhattarai, 50 yrs	Begnas
7	Devi Kanel, 39 yrs	Begnas
8	Mrs Buddha Jalari, 55 yrs	Begnas
9	Prem Jalari, 57 yrs	Begnas
10	Chiza Nepali, 46 yrs	Begnas
11	Charimaya Jalari, 76 yrs	Begnas
12	Gyanu Jalari, 49 yrs	Begnas
13	Shanti Maya Jalari, 50 yrs	Begnas
14	Bini Maya Jalari, 65 yrs	Begnas
15	Bishwanath Khanal, 60 yrs	Begnas
16	Rajendra Jalari, 52 yrs	Begnas
17	Syanu Jalari, 55 yrs	Begnas
18	Buddhi Nepali, 45 yrs	Begnas
19	Mukti Subedi, 61 yrs	Begnas

20	Padma Raj Subedi, 57 yrs	Phewa
21	Moti Raj B aral, 50 yrs	Phewa
22	Hom Bdr Kunwar, 65yrs	Phewa
23	Akkal Bdr Sunar, 58 yrs	Phewa
24	Prem Bhattarai, 62 yrs	Phewa
25	Sundar BK, 55 yrs	Phewa
26	Ram Paneru, 59 yrs	Phewa
27	Ramji Paudel, 68 yrs	Phewa
28	Mangal Bdr Nepali, 60 yrs	Phewa
29	Kali Bdr Nepal, 62 yrs	Phewa
30	Chuda Mani Pahari, 70 yrs	Phewa
31	Gyan Bdr Jalari, 55 yrs	Phewa
32	Hom Bdr Lamichhane, 65 yrs	Phewa
33	Laxman Thapa, 65yrs	Phewa
34	Mitra Mani Timsina, 55 yrs	Phewa
35	Prakash Baral, 65 yrs	Phewa
36	Punya Poudel, 65 yrs	Phewa
37	Rana Bdr Thapa, 60 yrs	Phewa
38	Krishna Adhikari, 62 yrs	Phewa
39	Debendra bdr Lamchhane, 65 yrs	Phewa
40	Tulasi Pageni, 70 yrs	Rupa
41	Chandra Kanta Pageni, 75 yrs	Rupa
42	Basundhari Adhikari, 70 yrs	Rupa
43	Tulasiram Adhikari, 91 yrs	Rupa
44	Santa Bdr Gurung, 60 yrs	Rupa
45	Santos Babu Poudel, 37 yrs	Rupa
46	Shivahari Ojha, 40 yrs	Rupa
47	Sumitra Adhikari, 59 yrs	Rupa
48	Ram Prasad Adhikari, 68 yrs	Rupa
49	Som Maya Gurung, 46 Yrs	Rupa
50	Ram KC, 60 yrs	Rupa
51	Hommaya Gurung, 60 yrs	Rupa
52	Jaya mangal Adhikari, 61 yrs	Rupa
53	Tak Bdr Grg, 62 yrs	Rupa
54	Bishnu Hari Adhikasri, 55 yrs	Rupa
55	Man Bdr Ale, 70 yrs	Rupa
56	Pabitra Jalari, 40 yrs	Rupa

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