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Risk assessment and management framework for rapidly spreading species in a Kashmir Himalayan Ramsar site

Iqra Jan · Saba Yaqoob · Zafar A. Reshi · Irfan Rashid · Manzoor A. Shah

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Abstract In view of huge ecological impacts and exorbitantly high economic costs of biological invasions, the risk assessment for timely prediction of potential invaders and their effective management assumes central importance, yet having been little addressed. Hence, we did the risk analysis of 39 plant species, including both alien and fast-spreading native species, in Hokera wetland, an important Ramsar site in Kashmir Himalaya, using the post-border Australian Weed Risk Management (AWRM) framework. Based on the AWRM scores, we listed these species into different categories, such as alert, destroy infestation, contain spread, manage weed, manage sites and monitor, with management implications. Out of the eight decisions created for Hokera wetland, alien *Alternanthera philoxeroides* was identified as 'alert species', while *Typha angustifolia, Typha latifolia, Phragmites australis, Sparganium ramosum* and *Myriophyllum aquaticum* were placed under the 'manage weed' category of the management priorities. To check the predictability and reliability of the AWRM scheme, we developed the receiver operating characteristic (ROC) curve that yielded a positive diagonal value of above 0.5, with 88.6% and 83.1% area under the curve for comparative weed risk (CWR) score and the feasibility of coordinated control (FOC) score, respectively. The outcomes of the ROC analysis were compared with the results of the WRM evaluation of other regions across the globe. Our results indicate that the risk assessment using the AWRM model is quite efficient at discriminating and flagging the most troublesome plant species and offsetting their impacts on native biodiversity and ecosystem functioning in wetland ecosystems. Given the growing threat of biological invasions in the protected areas, we recommend an integrated and strategic approach, well informed by the data on the species biology and ecology, in the form of the AWRM management system to effectively deal with the alarmingly spreading species.

Keywords Invasive species · Management Priorities · Native spreading species · Protected areas · Post-border weed risk assessment · ROC · WRM

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I. Jan · S. Yaqoob · Z. A. Reshi · I. Rashid · M. A. Shah (✉)
Department of Botany, University of Kashmir, Srinagar-190006, Jammu and Kashmir, India
e-mail: mashah@uok.edu.in

Introduction

The impacts of biological invasions are quite discernible, not only in disturbed habitats but also in the protected areas (PAs), such as National Parks and Ramsar sites. Of late, the invasive alien plants (IAPs) are reported to pose a severe threat to the protected areas (Foxcroft et al., 2017; Moodley et al., 2021) by way of changing the community structure and affecting the feeding ecology of wildlife thereof (Hejda et al., 2009). The stakeholders and the managers thus genuinely perceive the IAPs as a major problem and a critical barrier for managing the native communities (D'Antonio & Meyerson, 2002; Foxcroft et al., 2017). A recent assessment has tracked down the monetary expenses of invasive species within PAs to the tune of US$ 22.13 billion between 1976 and 2020, with US$ 802.47 million as observed costs and US$ 21.18 billion as potential costs (Moodley et al., 2021). These are still regarded as underestimates (Pyšek et al., 2013), as the loss of ecosystem services and ecological impacts in such economic cost models are not so straightforward. Therefore, early detection of IAPs using appropriate risk assessment frameworks can help a great deal in rapid response and timely management of biological invasions in the PAs of high conservation concern.

The risk assessment, which lies at the heart of invasive species policy and management, is a type of decision support instrument created to assist with the identification and management of spreading plants and to prioritize the invader species for management at multiple spatial scales (Anon, 2006; Downey et al., 2010a, 2010b). Risk appraisal frameworks for both pre-border screening (Hazard, 1988; Pheloung et al., 1999; Adams & Setterfield, 2016; Brock & Daehler, 2020 (Hawaii)) and post-border Weed Risk Management (for instance, Virtue et al., 2005; Anon, 2006; Virtue, 2008, 2010; Weber et al., 2009; Johnson & Charlton, 2010; Setterfield et al., 2010; Johnson & Charlton, 2010; Downey et al., 2010a, 2010b, 2011; Hamilton et al., 2014) have been developed to eradicate and contain new incursions. The WRM systems suggest a stepwise approach to evaluate both weed risk and feasibility of control resulting in management priority plans on the needed premise within a process of communication, interview, checking and review (Anon, 2006). The AWRM approach suggests staying away from, mitigating or enduring the risk of incursions found in protected areas (Johnson & Charlton, 2010).

Several Aquatic Weed Risk Assessment Models (AWRAM) based on pre-border weed risk analysis has been executed successfully to evaluate potential aquatic weeds in New Zealand (Champion & Clayton, 2001a, 2001b); Indiana (USA) (Gordon et al., 2012); South America (Lozano & Brundu, 2018); Florida (Gordon et al., 2011); and Europe (Champion et al., 2010). The Australian Weed Risk Assessment (AWRM) (Virtue & Melland, 2003, and Anon, 2006) based on the Australian and New Zealand's post-border protocols provides proper management action plans for containment or eradication of invasive species, which pre-border and most post-weed risk evaluations fail to give. Therefore, we adopted AWRM (Virtue & Melland, 2003; Anon, 2006) to deal with the invasion problem of PAs in Kashmir Himalaya. Besides, the post-border AWRM scheme is relatively less tested outside Australia as compared to the pre-border weed risk assessment for aquatic flora.

Some species have been recognized as invasive in their native range and referred to as 'native invader' by Simberloff (2011). It is pertinent to mention that a number of WRM systems (Downey et al., 2010a, 2010b; Randall et al., 2008; Booy et al., 2017), except Johnson (2009) and Sohrabi et al. (2020), often ignored the native spreaders and evaluated non-native species only instead. Being categorized as 'non-native or alien' is not an obligate criterion for management (Booth et al., 2003). The native species possessing traits largely similar to invasive alien plants can also cause economic and ecological impacts on the ecosystem and create an unusual set of challenges for science and management policy (Carey et al., 2012). Therefore prioritization systems like risk assessments, especially post-border, as a holistic approach assist to combat both native and non-native species incursions in the wetland.

Kashmir Himalaya has a network of protected areas. The inventories of the alien flora of Kashmir Himalaya documented so far (Khuroo et al., 2007; Shah & Reshi, 2014) indicate that these alien species have been introduced either unintentionally or deliberately for agriculture, forestry and horticulture (Reshi & Rashid, 2012). However, there is no specific mention of the issue of IAPs and the native spreading species in the PAs, despite being an emanating threat to these systems (Reshi et al., 2008). Of the Kashmir Himalayan wetland ecosystems the Ramsar sites are of special significance given their role in providing a variety of ecological and economic benefits, such as recreational and cultural value, role in flood control and nutrient cycling, as habitat of waterfowl and wildlife, to name a few (Costanza et al., 1997; Zedler & Kercher, 2005; Dar et al., 2020). The Hokera wetland Ramsar site is well known for diverse resident and migratory birds, yet significantly transformed by IAPs and some fast-spreading native plant species. This wetland used to be an ideal abode for species of high economic importance that have either disappeared (for instance, *Nelumbo nucifera, Euryale ferox* and *Acorus calamus*) or significantly decreased in abundance (such as *Trapa natans* and *Nymphoides paltatum*) (Khan, 2004; Bano et al., 2018), primarily due to a high infestation of IAPs.

Thus, taking advantage of the reliable existing post-border risk assessment frameworks for rapidly spreading species, the primary focus of this study was to outline the process used to identify species that pose the highest risk to the target Himalayan Ramsar site and devise a species-specific action plan and management strategy. Our specific questions included: (a) Which plant species pose the highest risk to the Hokera wetland regardless of being native or non-native and (b) whether the post-border AWRM framework is effective enough in identifying the high-risk species? Besides risk assessment, here we also clarify species nativity from all reliable sources that has been hitherto rather contradictory. The implications of the results obtained to tackle the problem of fast-spreading species for effective restoration and conservation of wetland ecosystems are discussed.

Materials and methods

Study site

Hokera wetland lies between 34°0’ to 34°10’ N and 74°40’ to 74°45’ E towards the northwest of Srinagar at an elevation of 1584 m above mean sea level with a Sub-Mediterranean climate. It is around 10 km away from the Srinagar city and is effectively accessible by the National Highway 1-A that connects Srinagar city to the Baramulla town of the Kashmir region. The dominant elements of vegetation found in Hokera wetland include *Typha angustifolia, Typha latifolia*, *Phragmites australis*, *Sparganium ramosum* and *Myriophyllum aquaticum.* The wetland used to be an important game reserve as it is an ideal abode for both migratory and resident waterfowl. The wetland harbours a large number of migratory birds in winter and provides a breeding ground for herons, egrets and rails (Foziah, 2009). The Hokera wetland is fed by the Doodganga channel going through the village Hajibagh situated on its southeast and other occasional channels like Soibugh and Dharmuna (Fig. 1).

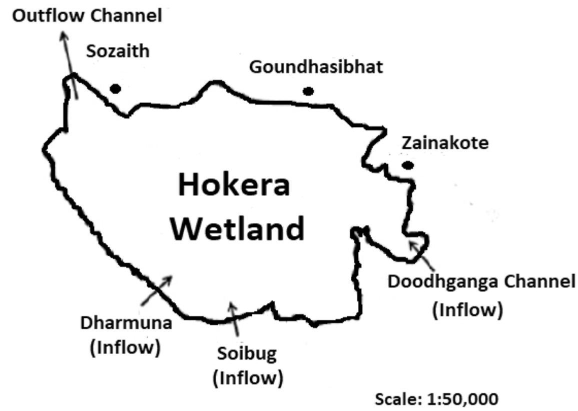


Fig. 1 Map of Hokera wetland showing the inflow and outflow channels

A populace of 72,000 individuals living in twelve hamlets encircles the wetland. This wetland has been declared as a Ramsar site (www.ramsar.org) with site number 1570.

Risk assessment

To detect new and existing intruder species attacks and assess the risk posed by problematic native species, we adopted the modified version of the Australian Weed Risk Management (AWRM) derived from Virtue and Melland (2003) and Anon (2006). The AWRM system was selected in view of being (i) a target assessment process that is worldwide perceived as a prime practice within a biosecurity context, (ii) a system that can support future weed management strategies, (iii) an important tool for the proper perception of the relative threat posed by species, (iv) a method that lessened impacts and expenses related to monitoring and management of noisy plant species through zeroing in on the most essential peril species first and (v) a better consolidation of weed management techniques and policy. The AWRM framework was used to calculate the risk score and the feasibility score of target plant species. This was the AWRM system that assisted us with computing the danger score and the possibility score of chosen plant species for better consolidations of invasive management strategies and policies.

AWRM stage 1—the WRM context for study site

The pioneering stage of AWRM builds up the unique situation to determine goals, scope, stakeholders, resources and methods to manage plant incursions. The stakeholder's feedback is especially significant in the weed context establishment and in providing support for any planned action (Mooney & Hobbs, 2000). This stage assists to refine and improve plant regulation procedures for highly spreading species, be native or alien. We explicitly considered the (a) requirements of weed specialists, botanists, ranchers, land directors and government organizations, (b) quarantine guidelines and rules created for India (http://ppqs.gov.in/) and (c) limit and supporting foundations. These considerations will empower the meaning of clear and attainable outputs and outcomes expected from undertaking the WRM evaluation.

AWRM stage 2—recognize weed risk plants

By using appropriate sources such as Germplasm Resource Information Network Taxonomy database for Species distribution (GRIN—https://npgsweb.ars-grin.gov/gringlobal/taxon/taxonomy), Plants of the World Online (POWO) by the Royal Botanic Gardens, Kew (POWO- http://www.plantsoftheworldonline.org/), CABIs International online weed database (https://www.cabi.org/) and published papers (Khuroo et al., 2007; Reshi & Rashid, 2012; Shah & Reshi, 2014; Bano et al., 2018), 39 plant species were identified for evaluation in stage 3. We also examined the herbarium specimens of these wetland plant species housed in Kashmir University Herbarium (KASH). Other than analysing selected species for their nativity, the species were also characterized based on their weedy and non-weedy nature using different published sources (Kaul & Usha, 1976; Khan, 2004; Narayan et al., 2017; Kumar et al., 2018; Bano et al., 2018).

AWRM stage 3—analysis and evaluation of weed risk

After the selection of 39 plant species, a score was generated for each plant species utilizing the scoring framework proposed by Virtue and Melland (2003). The questionnaire of AWRM consists of two sections, comparative weed risk (CWR) and the feasibility of coordinated control (FOC) score. At this stage, the CWR section was compiled and answered. This section was based on three key criteria questions consisting of 12 multiple-choice sub-question: (1) **Invasiveness** (five questions) that indicate how fast the weed can spread, (2) **Impact** (six questions) indicating how much potential impact the weed has, (3) **Potential distribution** (one question) to explain what extent of land use is at risk from the weeds. The context of the inquiry questions as used by Virtue and Melland (2003) was changed to Hokera wetland in Kashmir. We accumulated data from different sources, including the published literature (Adkins et al., 1996; Khuroo et al., 2007; Havel et al., 2015; Anderson et al., 2015; Zhang et al., 2021), online databases (www.cabi.org/isc/database, www.ars-grin.gov) and the internet (search engines based on the name of species). The species score of invasiveness part was divided by 15 (being maximum score) and multiplied by 10 to move the decimal point to the right in order to attain a round figure. The impact was also calculated by a similar process but divided by the maximum score of 19. The score for potential distribution remains intact with no change as it is out of 10 (Virtue & Melland, 2003). The total risk score was obtained by multiplying the scores of three criteria questions within the range of 0–1000. We created 20% frequency bands, by using frequency distribution of the calculated CWR scores following Virtue and Melland (2003). We selected the assigned description according to Sohrabi et al. (2020) for each level of CWR (Table 1).

AWRM stage 4—analysis and evaluation of the feasibility of control

At this stage, we used the feasibility of coordinated control (FOC) with the target of containment preferentially for native species (Sohrabi et al., 2020) and the same attribute feasibility of co-ordinated control (Anon, 2006) to target both containment and eradication specifically for invasive species (Virtue et al., 2008; Virtue, 2010). The three criteria questions of the FOC section consist of 10 sub-questions (1) **Control costs** (four questions) indicates the control cost of species per hectare in the first year, (2) **Current distribution** (two questions) indicates how widespread the weed inside the considered region and (3) **Persistence** (four questions) indicates how much time it takes to eradicate the weed. For each of the 39 considered

Table 1 Representative description for each of the weed risk level used for the target species

CWR level	Representative description
Very High	Species is a major invader and is known to impact native vegetation, environment and wildlife health. Immediate and sustained management is required.
High	Species is an important invader and poses a major threat to native vegetation, environment and wildlife health. Active management is required.
Medium	Species is an invader and poses a threat to native vegetation. Environment and wildlife health. Management is required.
Low	Species is a minor invader and poses a limited threat to native vegetation, environment and wildlife health. Management is advisable to limit spread.
Negligible	Species is marginal invader and poses a limited threat. Management should be focused on monitoring to ensure the status does not change.

plant species, the data identified with their control and containment inquiries inside the wetland were gathered and addressed utilizing various sources including web assets. The score of these three criteria questions was standardized using a range of 0–10 as in stage 3 and then multiplied to get a total FOC score. To develop a FOC priority, five similar frequency groups were created using 20% frequency bands wherein the higher the score, the lower the priority is (Table 4). Assigned description according to Sohrabi et al. (2020) selected for each level of FOC (Table 2) and checked every species against these assigned descriptions.

AWRM stage 5—determining weed management priorities

The CWR and FOC bands from stage 3 and stage 4 separately were utilized to compute the degree of risk and control for chosen species, which were then used to create a decision matrix as described in the AWRM assessment (Anon, 2006). Each cell of the matrix was assigned with a weed management decision with appropriate management action according to the risk and feasibility of containing the species. We created four priority levels and 16 management decision cells (Table 5) instead of 25 matrix cells. We merged the high and very high matrix cells for both the CWR level and the FOC level to reduce the number of management decisions because 25 management strategies were considered to be excessive and impractical for 39 species studied in Hokera wetland (Table 6). The detailed representative description for each management action is given in Pest Management Plan – Landscape South Australia Part 2, 2009 (https://landscape.sa.gov.au/files/sharedassets/south_east/plants_and_animals/pest-management-strategy-part-2-plan.pdf).

Receiver operator characteristic (ROC) analysis

To evaluate the predictive ability of the AWRM framework, receiver operating characteristic (ROC) analyses were done to generate area under curve (AUC). It ended up being a helpful tool for assessing

Table 2 Representative description for each of the FOC level used for the target species

FOC level	Representative description
Very High	Species can be contained easily with a minimal cost at all locations. Species is known from only a small number of locations. Control options are readily available.
High	Species can be readily contained without significant cost. Species has a limited distribution. Control options are readily available.
Medium	Species can be contained in most locations. Species is not widespread. Control options are readily available. Costs may be significant.
Low	Species can be contained in some locations. Species is widespread. Control options are available. Costs may be significant.
Negligible	There are no containment options available for this species to prevent its spread. Spread is extremely likely despite control. Costs are prohibitive.

the presentation of invasive species screening tests. We generated the ROC curve for the CWR scores and the FOC scores separately by plotting the specificity (false-positive rate) on the X-axis and the sensitivity (true-positive rate) on the Y-axis (Virtue et al., 2008) for all possible cut-off scores with the help of IBM SPSS Statistics data editor version 22. Sensitivity here refers to the proportion of true positives, and specificity is the proportion of true negatives.

The ROC curve for the comparative weed risk level was developed by comparing two groups, predicted risk level vs. observed risk level. Predicted risk level here refers to status predicted from the CWR of all species, which was generated from AWRM assessment. Higher the CWR, higher is the risk level. Observed risk level, on the other hand, refers to the actual status (prevailing in field) for both spreading and non-spreading species that was generated by thorough field studies supplemented by other sources such as CABI's International online weed database (www.cabi.org/isc/datasheet) and Global Invasive Species Database (GISD) (http://www.iucngisd.org/gisd/) (see the supplementary material). The ROC analysis of the FOC level was done with the same procedure taking the FOC score of species in one group, referred to as predicted FOC level, and the observed FOC status of species (whether feasible for control or not) taken in the other group of the dataset referred as actual FOC status to generate ROC curve in SPSS Statistics editor.

Establishing species nativity

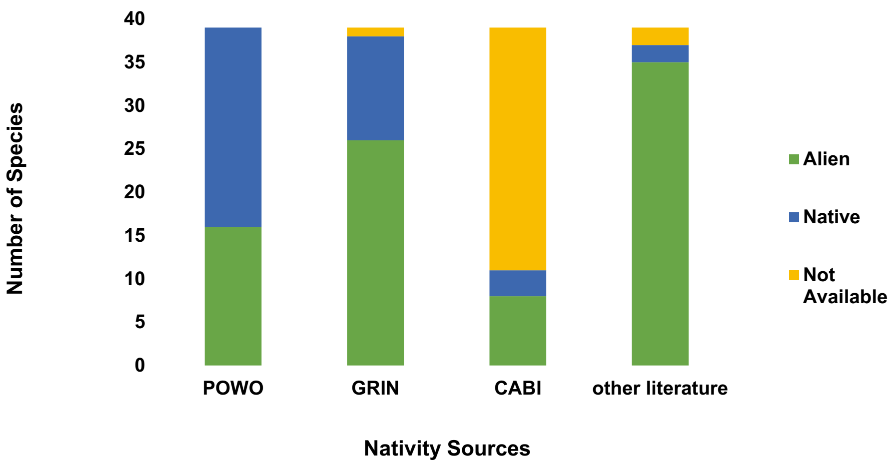
For establishing the species nativity, information from all major sources such as Germplasm Resource Information Network Taxonomy database for species distribution (GRIN—https://npgsweb.ars-grin.gov/gringlobal/taxon/taxonomy), Plants of the World Online (POWO) by the Royal Botanic Gardens, Kew (POWO- http://www.plantsoftheworldonline.org/), CABIs International online database (https://www.cabi.org/) and published papers (Bano et al., 2018; Khuroo et al., 2007; Shah & Reshi, 2014) was perused (see the supplementary material) (Fig. 2). Given the conflicting information from different sources, the final status of species nativity was considered preferably from the Plants of the World Online database (POWO, 2021). This source is supported by a huge expanding network that provides scope for the change in the species distribution as the database gets updated time and through.

Results

Study species

Overall 39 plant species belonging to 24 families were analysed by the AWRM framework, including 19 native and 20 non-native (alien) species. Among 20 alien plants, 18 were invasive species and all the

Fig. 2 Status of species nativity obtained from different sources



selected native species are highly spreading in Hokera wetland. These species belonged to 24 families, with Cyperaceae having a maximum of 5 species and Typhaceae and Lemnaceae 3 species each. All 39 selected species were aquatic including 25 emergent, 6 free-floating, 4 rooted floating and 4 submersed plant species.

Screening of 39 selected species for weedy nature, 28 species were found as weeds, and 11 species were non-weeds. Among the 19 native spreading species 14 species turned out to be weedy and 5 as non-weeds. However, of the 20 alien species, 13 species turned out to be weedy and 7 were non-weeds.

Range formation of bands and assigning of the risk level

The CWR score ranged from 34 to 432 and the FOC score ranged from 20 to 182 for the selected plant species. All the 39 plant species were assigned to one of the five weed risk groups (for instance, species with a CWR score greater than 346 (> 346) representing a higher risk level and species with a score less than 87 (< 87) taken as negligible risk level species (Table 3). The FOC score is different with an eminent distinction from the CWR score, as a higher FOC score (i.e. > 146) means feasibility of containment or control is less possible, therefore lesser the priority (i.e. inverse positioning: Table 4). The score from the FOC evaluation reflects the containment priority level allotted (for instance, species < 37 score will get a high priority level). Thus, the score from CWR and FOC assessment, respectively, indicates the risk and containment priority levels given to species (i.e. very high).

The CWR rating (stage 3)

We addressed all 12 questions of the CWR section for maximum species (32 species) and 11 questions for the remaining species, after a keen search from different sources for each species. Based on our results, 3 species were classified as a 'very high' risk species (*Sparganium ramosum, Phragmites australis*, *Typha latifolia*), 3 as high, 9 as a medium, 17 as low and 7 as negligible in the classified risk groups of CWR. Among the 19 native species 10 (53%) were classified as low-risk species, 5 (26%) as a medium, 2(11%) as negligible and 2(10%) as a high and very high-risk group, 5% each.

Table 3 The five CWR levels generated using 20% frequency bands for 39 aquatic species

Frequency Band	CWR score	Risk Level
80–100	> 346	Very High
60–80	> 260 to < 346	High
40–60	> 173 to < 260	Medium
20–40	> 87 to < 173	Low
0–20	< 87	Negligible

Table 4 The FOC levels generated using 20% frequency bands for 39 aquatic species

Frequency Band	FOC score	Risk Level
80–100	> 146	Negligible
60–80	> 110 to < 146	Low
40–60	> 73 to < 110	Medium
20–40	> 37 to < 73	High
0–20	< 37	Very High

The FOC rating (stage 4)

All 10 framed questions of the FOC section of WRM were answered for all the selected species. Based on the range score of species in bands, 6 species (Table 4). All 20 alien plants were distributed evenly to each of the five FOC groups. Of the 10 negligible species, 5 were alien, and 5 as native. Ten native species (53%), among the total 19 studied native species, were classified as very high and high FOC species, and the other 5 species belong species were classified as very high FOC group, 14 as high, 7 as a medium, 1 as low, 10 as negligible and 1 as alert to a negligible class and 4 in the medium FOC group. The remaining one species *Alternanthera philoxeroides* with zero FOC score in Hokera wetland classified as alert species.

The WRM matrix has resulted by transposing the comparative weed risk levels got from stage 3 and FOC levels from stage 4. Both levels were created using 20% frequency bands as laid out in the AWRM (Anon, 2006) (Table 5).

ROC analysis of CWR and FOC score

ROC curves were developed by running IBM SPSS statistics software for both CWR and FOC scoring systems. IBM SPSS statistics software calculated

Table 5 The weed risk management matrix created to give weed management decisions based on the CWR score relative to the feasibility of containing the species. The CWR levels are presented here in the rows, and the FOC levels are presented in the columns

		Feasibility of coordinated control				
		Negligible >146	Low >110	Medium >73	High or Very High <37	
Comparative Weed Risk Level	Negligible <87	LIMITED ACTION)	LIMITED ACTION	LIMITED ACTION	MONITOR (7)	
	Low <173	MANAGE WEEDS (2)	MANAGE WEEDS	MONITOR (2)	(MONITOR) (12)	
	Medium <260	MANAGE SITES (4)	MANAGE WEEDS (1)	CONTAIN SPREAD (3)	DESTROY INFESTATION (1)	ALERT (1)
	High or Very High >260	MANAGE SITES (4)	CONTAIN SPREAD (1)	DESTROY INFESTATION (1)	ERADICATE	

threshold values between predicted risk level and observed risk level, respect for both CWR and FOC scores separately. The area under the ROC curve was 88.6% with a 95% confidence interval range of 78–99% with a positive result (i.e. above the 0.5 diagonal value), indicating that the CWR scoring system gives satisfactory results. The same process done with the FOC score gave an area under the curve (AUC) 83.1% with a 95% confidence interval range of 64–100% with a positive result. ROC curves are presented in Fig. 3a and 3b for the CWR and FOC scoring systems, respectively.

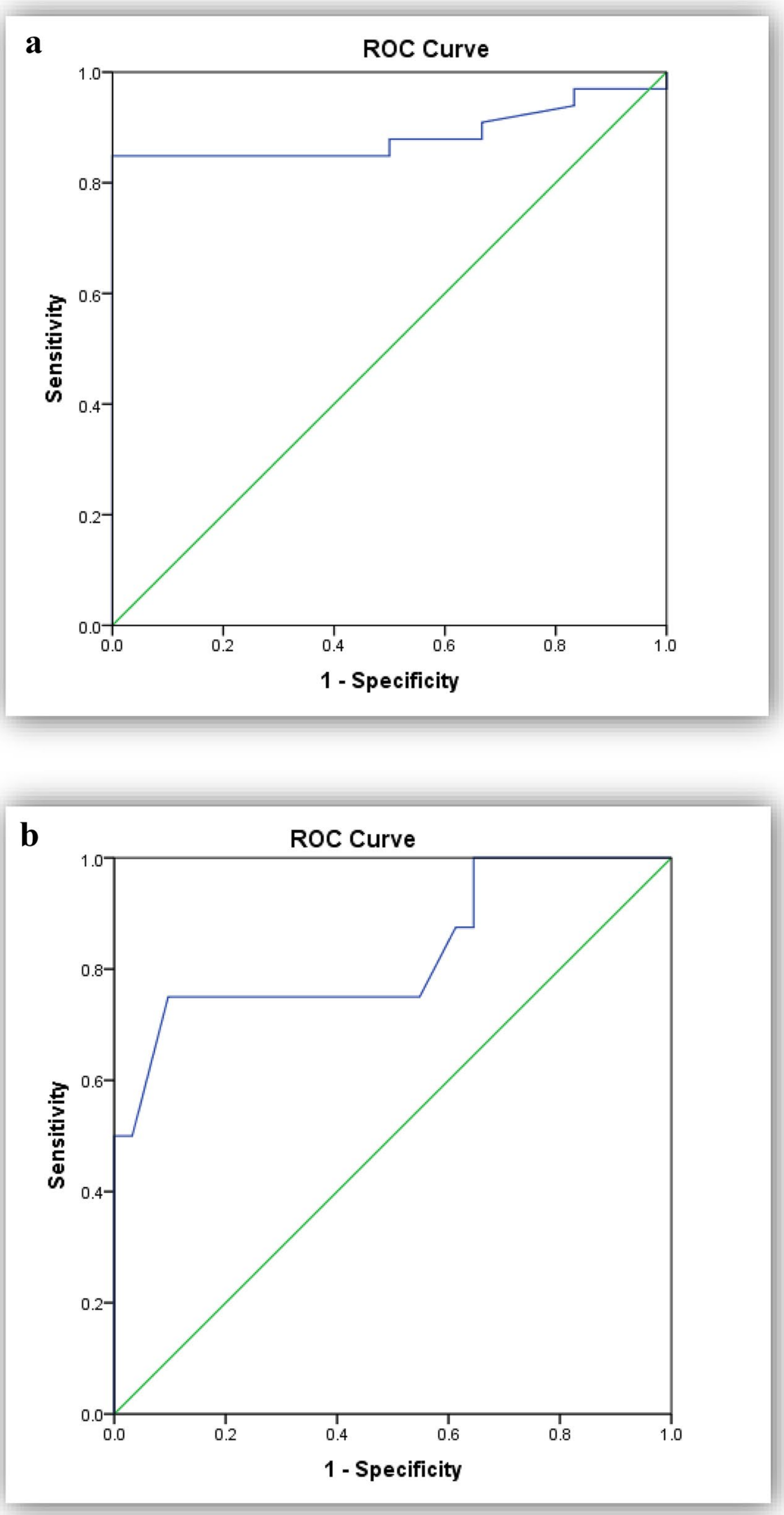
Determining management plans for Hokera wetland species using the WRM matrix

Strategic management decisions for the 39 plant species were determined through AWRM evaluation from the WRM matrix (Table 5), using representative description tables (Tables 1 and 2). We got 6 types of management decisions for 39 plant species, out of total 8 decisions designed for 39 plant species for Hokera wetland written in 16 matrix cells (Table 5). The species *Alternanthera philoxeroides* with zero FOC score was taken in the 'Alert' category of management. The species *Lemna gibba* and *Salvinia natans* were ranked under the "destroy infestation" category and *Azolla cristata*, *Bidens tripartita, Myriophyllum spicatum,* under the "contain spread" category. *Eleocharis palustris, Berula erecta* and *Myriophyllum aquaticum* were ranked in the "manage weed" category of the management matrix. Another eight species including *Phragmites australis, Sparganium ramosum, Typha angustifolia* and *Typha latifolia* with high CWR score and negligible FOC score placed under the "manage site" category include both native and alien species. Twenty-one species either with a negligible or low CWR score or with medium, high or very high FOC scores were assigned under the "monitor" category of management decisions.

Discussion

In view of the challenges faced by wetland managers for tackling invasive and fast-spreading native

Fig. 3 ROC curves between predicted status of species and actual status of species **a** curve between comparative weed risk score (predicted status) and actual status and **b** the feasibility of coordinated control score (predicted status) and actual status



species, the results of the present study on flagging the problematic species in Hokera wetland using the AWRM system have profound implications. The assessment is comprehensive enough in terms of sufficient information on the spreading nature, impacts, and current and potential distribution, persistence, and control costs that are used to assign different CWR and FOC scores. Specific recommendations via this WRM assessment for the target species in terms of 'species specificity' and 'different priority' strategies have been followed, such as 'alert', 'manage weed', 'manage sites', 'contain spread' and 'eradication' (Hamilton et al., 2014). This approach is highly useful to the wetland management authorities to factor into their management models for implementation on the ground. The highest risk species, with quite good feasibly for control, was found to be *Alternanthera philoxeroides,* which we recommend prioritizing first in the management plan followed *Lemna gibba, Salvinia natans*, *Azolla cristata*, *Spirodela polyrhiza, Myriophyllum spicatum* and *Bidens tripartite.*

Modifications in risk assesment

To understand the novelty of our results, it is important to clarify that many systems are working for post-border risk assessments (Hiebert, 1993; Weiss, 1999 (Australia); Champion & Clayton, 2001a, 2001b (New Zealand); Heffernan et al., 2001 (Virginia); Robertson et al., 2003 (South Africa); Orr, 2003; Gordon et al., 2008 (Florida)). However, these post-border risk assessments have failed to give proper management plans for the eradication and the containment of invasive species. Hence, we adopted the AWRM system, which overcomes the shortcomings in aforementioned frameworks and provides a better consolidation of weed management techniques and policy. The AWRM was used with few modifications, such as (a) recommending containment only (Sohrabi et al., 2020) for native problematic species as eradication of native species can never be materialized in a protected area, (b) suggesting both containment and eradication process for alien invasive species (Virtue et al., 2008; Virtue, 2010) depending on the strategic plan we got from decision management matrix (Table 5) and (c) the management decision matrix cells were reduced by merging high and very high categories to create only four priority levels and 16 management decision cells comprising eight management strategies for practical implications (Table 5).

Implications of the WRM

It is pertinent to mention that 28 species amongst the targeted species in this study (Table 6) have been reported as wetland weeds from Hokera by different workers (Kaul & Usha, 1976; Khan, 2004; Narayan et al., 2017; Bano et al., 2018; Kumar et al., 2018). However, such studies have limited scope in view of being a taxonomic inventory only without any management implications. For instance, many aquatic plants such as *Azolla cristata, Ceratophyllum demersum, Myriophyllum spp., Nymphoides peltatum, Potamogeton crispus, Sparganium ramosum* and *Salvinia natans* are reported prominent weedy species of the Hokera wetland (Habib, 2014), though they do not figure in the management plans anywhere. Also, Foziah (2009) suggested the removal of excessive invaders manually, but no prioritization of species was made for such a discourse. On the other side, the reintroduction of economically important native species, such as Nelumbo nucifera and Euryale ferox, was recommended by different researchers (Khan et al., 2004), but the effect of invaders on the reintroduction of these species was not taken into account. Since invasive species have an inherent capability to outcompete the native species (Stiers et al., 2011) for space and food, reintroduction of such native species seems inconceivable without controlling invasive species (Liebman & Janke, 1990; Zedler & Kercher, 2004), as they represent one of the most critical hindrances for re-establishing native ecosystems (D'Antonio & Meyerson, 2002; Shah et al., 2012). To fill these gaps, the present study assigned the risk level and feasibility level not only to alien invaders but also to native rapid spreaders, with a well-prioritized management plan for the problematic plants.

WRM of native species

The WRM system developed so far did not include native species for evaluation except in a couple of cases (Johnson, 2009; Sohrabi et al., 2020). We considered 19 native species for WRM testing. Many of these selected species such as *Alisma plantago-aquatica*, *Berula erecta*, *Epilobium hirsutum*, *Hydrocharis dubia, Lemna minor*, *Nymphoides peltata, Potamogeton natans*, *Ranunculus lingua*, *Schoenoplectus*

Table 6 CWR score and FOC score for 39 selected plants presented here with calculated risk and containment and control levels with the management plan

Species	Family	Aquatic plants (Types)	Alien/ Native	CWR Score	CWR Level	FOC Score	FOC Level	Management Plan	Weed/ Non-Weed
Alisma plantago-aquatica L	Alismataceae	Emergent	Native	90	Low	30	Very High	Monitor	Non Weed
Alternanthera philoxeroides (Mart.) Griseb	Amaranthaceae	Emergent	Alien	112	Low	0	Alert	Alert	Weed
Azolla cristata Kaulf	Salviniaceae	Free floating	Alien	301	High	82	Medium	Contain spread	Weed
Berula erecta (Huds.) Coville	Apiaceae	Emergent	Native	168	Low	155	Negligible	Manage sites	Non Weed
Bidens tripartita L	Astraceae	Emergent	Native	253	Medium	101	Medium	Contain spread	Non Weed
Butomus umbellatus Linn	Butomaceae	Emergent	Alien	69	Negligible	28	Very High	Monitor	Weed
Carex acutiformis Eheh	Cyperaceae	Emergent	Alien	59	Negligible	55	High	Monitor	Non Weed
Carex fedia Nees	Cyperaceae	Emergent	Alien	101	Low	61	High	Monitor	Weed
Carex pseudocyperus L	Cyperaceae	Emergent	Alien	211	Medium	152	Negligible	Manage sites	Non Weed
Ceratophyllum demersum L	Ceratophyllaceae	Submersed	Alien	59	Negligible	28	Very High	Monitor	Weed
Eleocharis palustris (L.) Roem. & Schult	Cyperaceae	Emergent	Alien	168	Low	152	Negligible	Manage sites	Non Weed
Epilobium hirsutum L	Onagraceae	Emergent	Native	124	Low	61	High	Monitor	Weed
Galium palustre L	Rubiaceae	Emergent	Alien	232	Medium	167	Negligible	Manage sites	Weed
Hippuris vulgaris L	Hippuridaceae	Emergent	Native	67	Negligible	30	Very High	Monitor	Weed
Hydrocharis dubia L	Hydrocharitaceae	Rooted Floating	Native	164	Low	45	High	Monitor	Weed
Lemna gibba L	Lemnaceae	Free floating	Alien	278	High	91	Medium	Destroy Infestation	Weed
Lemna minor L	Lemnaceae	Free floating	Native	126	Low	53	High	Monitor	Weed
Lycopus europaeus L	Lamiaceae	Emergent	Native	253	Medium	152	Negligible	Manage sites	Weed
Marsilea quadrifolia L	Lemnaceae	Free floating	Alien	168	Low	71	High	Monitor	Weed
Mentha aquatica L	Lamiaceae	Emergent	Alien	34	Negligible	30	Very High	Monitor	Non Weed
Menyanthes trifoliata L	Menyanthaceae	Emergent	Native	253	Medium	152	Negligible	Manage sites	Non weed
Myriophyllum aquaticum (Vell.) Verdc	Haloragaceae	Emergent	Alien	246	Medium	133	Low	Manage weed	Non weed

Table 6 (continued)

Species	Family	Aquatic plants (Types)	Alien/ Native	CWR Score	CWR Level	FOC Score	FOC Level	Management Plan	Weed/ Non-Weed
Myriophyllum spicatum L	Haloragaceae	Emergent	Native	208	Medium	89	Medium	Contain spread	Weed
Nymphaea odorata Aiton	Nymphaeaceae	Rooted Floating	Alien	112	Low	51	High	Monitor	Weed
Nymphoides peltata (S. G. Gmel.) Kuntze	Menyanthaceae	Rooted Floating	Native	103	Low	67	High	Monitor	Weed
Phragmites australis(cav.) Trin.ex Steud	Poaceae	Emergent	Native	401	V high	167	Negligible	Manage sites	Weed
Polygonum hydropiper L	Polygonaceae	Emergent	Alien	114	Low	48	High	Monitor	Weed
Potamogeton crispus L	Potamogetonaceae	Submersed	Native	42	Negligible	51	High	Monitor	Weed
Potamogeton natans L	Potamogetonaceae	Submersed	Native	124	Low	83	Medium	Monitor	Weed
Ranunculus lingua L	Ranunculaceae	Emergent	Native	144	Low	73	High	Monitor	Non Weed
Rumex nepalensis Spreng	Polygonaceae	Emergent	Alien	38	Negligible	20	Very High	Monitor	Weed
Sagittaria cuneata E.Sheld	Alismataceae	Emergent	Alien	101	Low	73	High	Monitor	Non Weed
Salvinia natans (L.) All	Salviniaceae	Free floating	Native	253	Medium	61	High	Destroy Infestation	Weed
Schoenoplectus lacustris (L.) Palla	Cyperaceae	Emergent	Native	147	Low	81	Medium	Monitor	Weed
Sparganium ramosum Heuds *(S. erectum* L.*)*	Typhaceae	Emergent	Alien	432	V high	182	Negligible	Manage sites	Weed
Spirodela polyrhiza (L.) Schleid	Araceae	Free floating	Alien	185	Medium	91	Medium	Contain Spread	Weed
Trapa natans L	Lythraceae	Rooted Floating	Native	118	Low	73	High	Monitor	Weed
Typha angustifolia L	Typhaceae	Emergent	Native	324	High	182	Negligible	Manage sites	Weed
Typha latifolia L	Typhaceae	Emergent	Alien	371	V high	152	Negligible	Manage sites	Weed

lacustris, Trapa natans, Bidens tripartite, Lycopus europaeus, *Menyanthes trifoliata*, *Myriophyllum spicatum*, *Salvinia natans, Hippuris vulgaris* and *Potamogeton crispus,* were considered as alien by previous studies (Khuroo et al., 2007; Shah & Reshi, 2014). However, after checking the status on the POWO, these species turned out to be native. The reason for their misinterpretation might be because of their fast-spreading nature which has the potential to pose threat to the overall biodiversity of wetland. Therefore, we took these spreading native species also into account for the AWRM testing to understand the risk posed by them. After evaluating our target native species, 53% of the species impose the low risk, 26% medium risk, 11% negligible risk to the wetland. Only two species (10%) impose high risk (*Phragmites australis* and *Typha angustifolia*) to wetland. This clearly shows that the majority of the target native species can be contained feasibly without significant cost.

Management outcomes for Hokera wetland species

Alternanthera philoxeroides was identified as a species with the highest management priority through AWRM analysis and documented as the highly invasive species for the wetlands of Kashmir Himalaya (Keller et al., 2018; Masoodi & Khan, 2012; Masoodi et al., 2013). The plant has zero FOC score as it is not sighted yet at the study site, but the resemblance of the habitat of species with Hokera wetland and AWRM evaluation of species with high risk score (CWR) predicted *A. philoxeroides* as alert species under 'alert category' of management strategies. It is predicted as a potential risk plant for Hokera Wetland, as it can take entry in predicted site at any time in the future. Therefore continue observation will help us in early detection and rapid response (EDRR).

The next management priority plan taken into consideration is 'destroy infestation'. Two species *Lemna gibba* and native, *Salvinia natans* were placed in this category which aims at the destruction of all infestations. Besides, these species have been documented as weedy species by different studies (Bano et al., 2018; Kaul & Usha, 1976; Kumar et al., 2018). Therefore, the reduction of species needs to be monitored continuously. Both species are free-floating species and can be eradicated at feasible sites using mechanical harvesting control methods (De Winton et al., 2013). *Azolla cristata*, *Spirodela polyrhiza, Myriophyllum spicatum* and *Bidens tripartita* were placed in the 'contain spread' category, which aims to prevent the extent of spreading species by preventing its entry and movement in the wetland and monitoring change in its current distribution. *A. cristata* and *S. polyrhiza* have been documented as free-floating weedy species (Kaul & Usha, 1976; Keller et al., 2018) that can be eradicated through mechanical harvesting, though *Myriophyllum spicatum* can be better removed through suction dredging along with their root system (Boylen et al., 1996; Clayton, 1996).

The next priority for the management is given to *Eleocharis palustris, Berula erecta and Myriophyllum aquaticum*, with medium CWR and low FOC score under the 'manage weed' plan. The targeted management through mowing, tilling, use of herbicides and/or biological treatments could be feasible (Hussner et al., 2017) to reduce the overall economic, environmental and/or social impacts from such weedy species,

The four high-risk and weedy species *Phragmites australis, Sparganium ramosum, Typha latifolia* and *Typha angustifolia* are quite dominant in Hokera wetland (Mir et al., 2009; Bano et al., 2018) and thus of management concern. These species also have been documented noxious wetland weeds elsewhere in Australia (Kay & Hoyle, 2001), North America (Finkelstein, 2003); Great Lakes (Trebitz & Taylor, 2007; Tulbure et al., 2007) and Indian wetlands (Gopal & Sharma, 1982; Khan & Shah, 2010). The huge inflow of wastes and the silt containing nitrate and ammonical nitrogen from the residential areas into the wetlands (Bhat & Pandit, 2014) boosts the excessive growth of macrophytic vegetation (Sharma & Gopal, 1982; Pandit & Kumar, 2006) in Hokera wetland (Dar et al., 2014), especially *P. australis, S. ramosum* and *T. angustifolia,* thereby converting marshy areas into rather a terrestrial grassland-type systems. It has resulted in the decrease of wetland area from 18.75 km^2 in 1969 to 13 km^2 in 2008 with a drastic change of the open water area from 1.74 km^2 in 1969 to 0.31 km^2 in 2005 (Romshoo & Rashid, 2014). Previous studies have highlighted many factors like anthropogenic pressures, drastic hydrological fluctuations (Coops & Hosper, 2002), siltation and human settlements, and floods of 2014 (Bhatt et al., 2017) are responsible for changing the LULC of the wetland (Khan et al., 2004). Besides, invasive species spread impacted badly the food production for the avifauna (Khan, 2004), which in turn has brought about a sensational fall in the appearance of birds (French et al., 2008) visiting Hokera wetland (Asian Water Bird Census, 2020) and hence calls for its timely eco-restoration and management (Dar et al., 2020). These species with high CWR and negligible FOC score need to be contained under the 'manage site' category, where the focus has to be laid on identifying the key sites to prevent their spread which is done by surveillance and mapping. Controlling of infestations and switching their current scattering within and in close proximity to key positions has to be monitored. Otherwise, eradication and containment of species with negligible FOC score are difficult as it requires high labour cost and logistic support. Based on our surveys in and around the wetland for the last two years, we recommend increasing the open water area by targeting the sites of these spreading species and increasing the depth of the wetland (Fredrickson & Reid, 1988; Smith et al., 2004). For water-level management, structures like traditional floodgates, winching systems, penstocks and sluice gates should be used to restore natural hydrological processes (Rampano, 2009), which ensures the water flow with the desired volume and periodicity. Installing sewage treatment plants at the inlet points of the Hokera wetland could help regulate water quality in the wetland and thereby restrict the establishment of alien invasive flora. The wetland managers, however, need to consider other values of plant communities in terms of being the nesting, breeding and feeding sites for resident and migratory birds (Romshoo & Rashid, 2014). Nevertheless, many waterfowl species need open water areas as well and thus maintaining the critical ratio of vegetation cover vs. open water is important for supporting the ideal diversity of avifauna.

Another two alien species *Carex pseudocyperus* and *Galium palustre*, and two native species *Lycopus europaeus* and *Menyanthes trifoliata* that pose either low or medium risk also suggested to manage under the 'manage site' category. Ten alien species (Table 5) seem to be of negligible or low risk to wetland, the spread of which needs to be monitored by measuring the change of abundance in species continuously.

ROC evaluations

Different WRA evaluations have utilized ROC analysis to comprehend the discriminatory nature of the risk analysis being assessed (Caley & Kuhnert, 2006; Virtue et al., 2008). From ROC analysis, we got the mean area under curve 88.6% (Fig. 3a), which is comparable with the results of the AWRA system with 89% mean area under the curve (AUC) in Australia (Caley & Kuhnert, 2006) and 89.5% for a risk assessment designed for botanic gardens (Virtue et al., 2008). On the other side, ROC results of Iran evaluation showed 62% mean AUC for CWR and 72% for FOC of species (Sohrabi et al., 2020), which reflects a relatively lower value than our results of ROC evaluation. The plausible explanation for this difference could be that (a) greatest inquiries of the AWRM testing were endeavoured, which builds the worth of AUC. (b) The differences in the ROC results can account for the differences in the distribution of weed risk scores for risk levels, using the 20% frequency bands between our dataset and that of Sohrabi et al. (2020) and (c) the difference in results is also expected because of the variation in the dataset of species used and the differed geographical locations. These ROC results indicate that the AWRM has an extraordinary potential to discriminate between the spreading and non-reading species.

Conclusions

While undertaking the risk assessment, one of the spinoffs of this study is authentication of species nativity, which hitherto had rather contradictory status. For instance, many species that were considered alien by earlier studies (Khuroo et al., 2007; Shah & Reshi, 2014), turned out to be native after our analysis. While we used all major aforementioned reliable sources for this purpose, in case of the conflicting information from different sources the final status of species nativity was considered preferably based on the plants of the world online database (POWO, 2021). This is because of the fact that this source is supported by a huge expanding network that provides scope for the change in the species distribution as the database gets updated with time. In conclusion, the results of this study promise to be of immense value to wetland managers to deal with the weedy and fast-spreading species in a better and targeted way. Though several risk assessment schemes have been designed over the years to identify the potential invasive species, our results lend support for the feasibility of the Australian Weed Risk Management (AWRM) for its precision in identifying the species of high concern for control, eradication or management in the PAs. Overall, the AWRM evaluation is an effective approach to assess the risk posed by invasive species with quite a high predictive rate provided we have adequate data accessible to address a larger part of inquiries of this scheme.

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Declarations

Conflicts of interests The authors hereby declare no conflict of interest and that t'here are no competing interests too.

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