Identifying threats from invasive alien species in Bangladesh

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ABSTRACT

Bangladesh has a long history of species introductions from different geographic regions. The country was a major international trade route during the early-modern era and was under British colonial rule until 1947. During this time, many invasive alien species (IAS) that now threaten the country’s native flora, fauna and ecosystems were inadvertently introduced. In recent years, deliberate preferences for fast-growing, high-yielding exotic species has also threatened the existence of native species in the country. Here, we provide an overview of IAS in Bangladesh, their suspected origin, the purpose of their introduction, and their impacts on ecosystems and people. Based on a literature review, we identified 69 IAS reported to occur in Bangladesh. The majority of these species were plants (46 species), followed by fish (16 species), and insects (5 species). The identified species were introduced from South America, Asia, Africa and Australia, primarily to provide food and timber. Although initially introduced to favor the productivity of food and timber, and to provide certain environmental benefits, the identified IAS are increasingly threatening native flora, fauna and ecosystems in Bangladesh. We recommend a need for appropriate policies and legislation to address the introduction, monitoring, and regulation of IAS in the country. A comprehensive list of IAS and a robust protocol to differentiate harmful from advantageous species is also necessary. Community awareness, advocacy, surveillance, capacity building of government officials, and cooperation with neighboring countries for transboundary management and monitoring of IAS is also important to minimize the risks posed by IAS in Bangladesh.

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1. Introduction

Invasive alien species (IAS) have gained wider recognition by scientists and policymakers in the past decades due to their severe ecological and economic impacts worldwide (Turbelin et al., 2017; GISp, 2004). Globally, IAS are considered one of the greatest threats to native ecosystems, and biodiversity (Guido and Pillar, 2017; Early et al., 2016; Padmanaba and Corlett, 2014). Increasing globalization including human-mediated transport beyond biogeographic barriers has led...
to the arrival of IAS in new regions, and environmental changes, including global warming, facilitate their establishment in new regions (Dawson et al., 2017; Early et al., 2016; Masters and Norgrove, 2010; Walther et al., 2009; Meyerson and Mooney, 2007). In many natural environments, although the introduction of some IAS may initially be beneficial in terms of productivity and some ecosystem services, in the long-term, there is likely to be a sharp fall in those services and/or benefits (Marchante et al., 2020; Vila et al., 2011). Many IAS are also recognised for their rapid growth, large reproductive output, efficient dispersal capabilities, and tolerance to a broad range of environmental conditions that positively influence their ability to adapt and reproduce to the detriment of native species (Hellmann et al., 2008; Campbell, 2005; Wittenberg and Cock, 2001).

Bangladesh has a long history of species introductions from different countries or geographic regions (Barua et al., 2001). The country was part of a major international trade route during the early-modern era and was under British colonial rule until 1947 (Poffenberger et al., 2000). Geographically, the country is bordered by India in the west, north and east, except for a small portion in the southeast where it is bordered by Myanmar (Rashid, 1991, Fig. 1). The majority of Bangladesh’s land mass is formed by river alluvium from the Ganges and Brahmaputra rivers and their tributaries (Brammer, 2016). More than fifty transboundary rivers feed into the country, effectively creating the world’s largest delta, and second-largest riverine drainage basin, the Ganges-Brahmaputra-Meghna (GBM) basin (Rasul, 2015). The majority of the country’s lands are arable (Brammer, 2016). Agriculture is, therefore, the dominant land-use, comprising nearly 65% of the total land area, followed by forests (17.5%), urban and built-up areas (8%) and water bodies (Mukul et al., 2014). Forests occupy nearly 2.53 million hectares and these forests are highly degraded in many areas except in the Sundarbans mangrove forests which are relatively rich in carbon and growing stock due to the restricted access by people (Mukul et al., 2018; Ishtiaque et al., 2016). Together with hill forests, the Sundarbans also represent the most biodiverse ecosystem in Bangladesh (Mukul et al., 2020).

Although a relatively small country, due to its unique geo-climatic conditions, Bangladesh is exceptionally endowed with a rich variety of flora and fauna (Mukul et al., 2018). At least 133 species of mammals, 711 species of birds, 173 species of reptiles, 64 species of amphibians, 742 species of fish (marine and freshwater), 479 species of mollusk, 323 butterfly species and 46 species of echinoderms have been recorded from the country (DoE, 2015; IUCN, 2015). In terms of flora, 3611 species of angiosperms, 7 species of gymnosperms and 195 species of pteridophytes are believed to occur in the country (Irfanullah, 2011; Ahmed et al., 2008a). Many of these species, however, are under threat due to overexploitation, habitat loss, urbanization and changing climate (Mukul et al., 2019, 2017; 2012; Alamgir et al., 2015).

A complete and reliable list of IAS in Bangladesh is still lacking. More than 300 exotic species are assumed to have been either domesticated or cultivated in the country at different times, of which there are no records (Hossain and Pasha, 2001). Several plant species mainly herbs and shrubs, were introduced into the country during the British colonial period for their

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**Fig. 1.** Location map of Bangladesh with major vegetation types and coverage.
aesthetic value (Ali, 1991). Most of the country’s timber producing species were introduced during the late 1980s to meet rapidly growing demand for timber, fuelwood, and fodder (Ahmed et al., 2008a; Khan et al., 2007; Mukul et al., 2006). In recent years, some fish species have been introduced into the country to increase productivity and support the nutritional needs of a large and growing population (Galib and Mohsin, 2010; Hossain, 2009).

Although the issue of IAS is a growing reality in Bangladesh, such species are still overlooked in relevant policies and sectoral management plans (Mukul et al., 2006). Based on a systematic literature review, this paper attempts to provide an overview of the IAS of Bangladesh, including their introduction pathways and purposes, their current occurrence, and their impacts on ecosystems and people. Using Bangladesh as the focal country, the paper also provides policy guidelines for better management of IAS in a more connected and globalized world in order to safeguard local biodiversity, ecosystems and livelihoods.

2. Data sources and analysis

We used the Web of Science (WoS) as an initial guide to the international scientific literature. We searched using combinations of keywords such as: “invasive species”, “invaser”, “alien species”, “exotic species” and “Bangladesh” either as topic or title, and using a timespan of “2000–2020”. Our WoS literature search yielded only 12 publications (see — Hossain et al., 2016; Galib, 2015; Al-Mamun et al., 2013; Uddin et al., 2013; Biswas et al., 2012, 2007; Khan et al., 2011; Rana and Akhter, 2010; Rana et al., 2010; Ahmed et al., 2008b, 2007). We, therefore, also made use of Google Scholar, which includes a wider range of local and regional journals, book chapters. Finally, we searched widely on Google, which locates grey-literature publications, such as country reports and proceedings articles that are not included in the scholarly databases. These searches were iterative and produced overlapping lists of publications. Our final list was comprised of 29 documents, including 18 journal articles, 7 technical reports, 1 book chapter, and 3 other documents (Supplementary material 1).

We categorized the IAS based on taxonomic groups (i.e. plants, birds, fish, insects, mollusc). We also considered their habitat types (e.g. terrestrial vs aquatic, agricultural, forest, waste and fallow lands) and extracted the possible origin of all species (continent or country, when possible), the period of their introduction (pre-independence, i.e. before 1971, and post-independence, after 1971), usage and major purpose of their introduction (e.g. food, timber, ornamental), their occurrence (common, moderately common, rare), mode of regeneration (naturally growing vs planted/cultivated), and likely impacts on ecosystems and people. While classifying the identified IAS into three broad categories (viz. highly invasive, invasive and potentially invasive), we considered their severity of damage and magnitude of spread. Any species without a clearly defined impact on environment were excluded from our list. For assessing the broader impacts of identified IAS on people’s lives and society, we considered issues such as economic losses incurred by their management and eradication, and losses in productivity of native species. We used descriptive statistics to present our findings and used suitable graphs and figures, whenever possible.

3. Results

3.1. The occurrence and origin of invasive alien species in Bangladesh

Altogether, we identified 69 IAS reported to occur in Bangladesh belonging to 36 families (Table 1). These species were introduced both intentionally and/or accidently. The majority of the species were plants (46 species; 66.7%), followed by fish (16 species; 23.2%) and insects (5 species; 7.3%). Among the identified IAS, 42.1% (29 species) were introduced from South America, followed by 24.7% (17 species) from other parts of Asia, 13.1% (9 species) from Africa and 10.2% (7 species) from Australia (Fig. 2). About 55.1% (38 species) of the recorded IAS were brought into the country before independence (i.e. before 1971), mostly during the colonial period, while the rest of the species (44.9%) were introduced more recently during the post-independent period (i.e. after 1971), mainly to meet Bangladesh’s growing demand for food and timber.

Some of the world’s worst IAS such as Chromolaena odorata, Lantana camara and Mikania micrantha, are found to be abundant in Bangladesh and are having detrimental impacts on local ecosystems (Islam et al., 2003; Barua et al., 2001, Fig. 3). Among the fauna, most of the reported IAS were fish and mostly species of carp (Barua et al., 2001). Other invasive alien fauna included a bird species (Columba livia), several insects and a species of mollusk (Achatina fulica). This list, however, is likely to be an underestimate of the actual situation of IAS in Bangladesh.

3.2. Invasive alien species in major ecosystems of Bangladesh and pathways of their introduction

Among the identified IAS, 66.7% (46 species) were found in terrestrial ecosystems and 33.3% (23 species) were found in aquatic ecosystems. In terrestrial ecosystems, the majority (86.7%) of the identified IAS were plants, while in aquatic ecosystems the majority were fishes (66.7%) (Fig. 4). In the terrestrial environment, many of the IAS are now widespread in more than one ecosystem (Fig. 5). For example, the invasive alien plants Lantana camara and Urena lobata are reported both from forest, and waste and fallow lands, whereas species like Acanthospermum hispidum, Cestrum diurnum, and Evolvulus nummularius can be found both in agricultural land and waste and fallow lands mainly as noxious weeds (Hossain and Pasha, 200). Species such as Agretum conyzoides, Chromolaena odorata, and Mikania micrantha are found to be abundant both in forests, agricultural land, and waste and fallow lands.
Table 1
Invasive alien species (IAS) reported from different ecosystems of Bangladesh.

| Life form | Family            | Scientific name                  | Common name       | Origin            | Habitat type(s) | Usage Occurrence | Mode of regeneration | Level of invasiveness | Source(s) |
|-----------|-------------------|----------------------------------|-------------------|-------------------|-----------------|-------------------|-----------------------|------------------------|-----------|
| Bird      | Columbidae        | Columba livia                    | Rock pigeon       | Europe            | TER             | P                 | +++                   | NG                     | HI 1, 2   |
|           | Claridae          | Claris gariespinus               | Adelaide            | Africa            | AQU             | F                 | +++                   | NG                     | HI 1, 2   |
| Cyprinida | Aristicthus nobilis| Goldfish                        | Bighead carp       | China             | AQU             | F                 | +++                   | NG                     | HI 2, 3   |
|           | Carassius auratus | Grass carp                      | Chinese           | Russia            | AQU             | O                 | C                     | I                      | 2         |
|           | Ctenopharyngodon idella | Common carp     | China, Russia      | China, Russia     | AQU             | F                 | +++                   | NG                     | HI 1, 2, 3 |
|           | Hypophthalmichthys molitrix | Silver carp  | China, Russia      | China, Russia     | AQU             | F                 | +++                   | NG                     | HI 1, 2, 3 |
|           | Mylopharyngodon piceus | Black carp       | China             | AQU               | F                 | +++                   | NG                     | HI 2       |
| Cichlida  | Puntius gonionotus | Thai sarpunti                  | Thailand           | AQU               | F                 | +++                   | NG                     | HI 2       |
|           | Oreochromis mossambicus | Common tilapia | Africa            | AQU               | F                 | +++                   | NG                     | HI 2       |
|           | Oreochromis niloticus | Common tilapia | Africa            | AQU               | F                 | +++                   | NG                     | HI 2, 3   |
|           | Pterygoplichthys multiradiatus | Armored fish | NA                | AQU               | O                 | ++                     | C                      | HI 1       |
|           | Trichopodus pectoralis | Siamese gourami | Thailand, Cambodia | AQU               | F, O             | ++                     | NG                     | HI 2       |
| Pangasiidae | Pangasius sutchi | Pangasius              | Thailand           | AQU               | F                 | +++                   | NG                     | HI 2       |
|           | Pangasius sanwongsei | Pangasius                 | NA                | AQU               | F                 | +++                   | NG                     | HI 2       |
| Poeciliidae | Gambusia affinis | Mosquito fish               | Armenia, Mexico    | AQU               | O                 | +++                   | NG                     | HI 1       |
|           | Poecilia reticulatus | Guppy                  | South America      | AQU               | F                 | +++                   | NG                     | HI 2       |
| Insect    | Aleyrodidae       | Bemisia tabaci               | Silverleaf whitefly | NA                | TER, AGR        | P                 | ++                     | NG                     | HI 1       |
| Dermetidae | Trogoderma granarum | Khapra beetle              | India             | AQU               | P                 | ++                     | NG                     | HI 1       |
| Formicidae | Paratrechina longicornis | Crazy ant         | Africa             | AQU               | P                 | +++                   | NG                     | HI 1       |
|           | Tapinoma melanocephalum | Ghost ant        | Africa             | AQU               | P                 | +++                   | NG                     | HI 1       |
| Lividae  | Diaphorina citri | Asian citrus psyllid       | Asia              | AQU               | P                 | +++                   | NG                     | HI 1       |
| Mullusk  | Achatinidae       | Achatina fulica              | Giant African land snail | Africa           | TER             | P                 | ++                     | NG                     | I 1       |
| Plant    | Alternanthera floroida | Joseph's coat     | South America      | TER, WF           | W                 | ++                     | NG                     | I 1, 5     |
|           | Alternanthera phloxoeides | Alligator weed  | South America      | AQU               | W                 | ++                     | NG                     | I 1, 6     |
| Asteraceae | Acanthospermum hispidum | Hispid starburr | South America      | TER, AGR, WF      | W                 | +++                   | NG                     | I 5, 10     |
|           | Ageratum conyzoides | Billy goat weed          | South America      | TER, FOR, AGR, WF | W                 | +++                   | NG                     | HI 1, 4, 5, 7, 8, 10 |
|           | Chromolaena odorata | Siam weed               | South America      | TER, FOR, AGR, WF | W                 | +++                   | NG                     | HI 1, 4, 5, 7, 9, 10 |
|           | Cyninthium cinereum | Little ironweed          | Africa             | TER, AGR, WF      | W                 | ++                     | NG                     | I 8       |
|           | Mikania micrantha | Mile-a-minute weed       | South America      | TER, FOR, AGR, WF | W                 | +++                   | NG                     | HI 5, 8, 9, 10 |
|           | Parthenium hysterophorus | Carrot grass     | South America      | TER, FOR, AGR, WF | W                 | +++                   | NG                     | HI 9       |
| Brassicaceae | Cardamine flexuosa | Wavy bittercress         | Europe             | TER, AGR, WF      | W                 | ++                     | NG                     | HI 1       |
| Commelinaceae | Commelina obliqua | Day flower              | Java               | TER, WF, Fo       | W                 | ++                     | NG                     | I 4, 5     |
| Convolvulaceae | Convvolus arvensis | Binweed               | Europe             | TER, WF           | W                 | ++                     | NG                     | I 4, 5     |
|           | Cuscuta reflexa | Giant dodder             | Europe             | TER, AGR, WF      | W                 | +++                   | NG                     | HI 8       |
|           | Evolulus nummularius | Roundleaf blindweed | West Indies        | TER, AGR, WF      | W                 | ++                     | NG                     | I 4, 5     |
|           | Ipomoea carnea | Pink morning glory       | South America      | AQU               | W                 | +++                   | NG                     | HI 4, 5, 9, 10 |
| Cyperaceae | Cyperus rotundus | Nut grass               | Africa, Europe     | TER, AGR, WF      | W                 | +++                   | NG                     | HI 1, 8    |
| Euphorbiaceae | Croton        | South America           | W                 | +++                   | NG                     | I 4, 5, 8    |
Table 1 (continued)

| Life form | Family | Scientific name | Common name | Origin | Habitat type(s) | Usage | Occurrence | Mode of regeneration | Level of invasiveness | Source(s) |
|-----------|--------|----------------|-------------|--------|----------------|-------|------------|---------------------|----------------------|------------|
| Pod | Fabaceae | Crotalaria bonplandianum | False | Australia and Pacific | TER; AGR | Ti, Ni | +++ | P | I | 1, 4, 5, 7, 11, 12 | |
| Pod | Fabaceae | Acacia auriculiformis | Black wattle | Australia and Pacific | TER; FOR | Ti, Ni | +++ | P | I | 1, 4, 5, 7, 11, 12 | |
| Pod | Fabaceae | Acacia mangium | Wild pigeonpea | Australia | TER; FOR | Ti, Ni | +++ | P | I | 1, 4, 5, 7, 11, 12 | 4, 5 |
| Pod | Fabaceae | Falcataria moluccana | Malacana koreana | Australia and Pacific | TER; FOR | Ti, Ni | +++ | P | I | 8, 12 | |
| Pod | Fabaceae | Leucaena leucocephala | Wild tamarind | South America | TER; FOR | Fo, Ni | +++ | NG | HI | 1, 4, 5, 11 | |
| Pod | Fabaceae | Mimosa pudica | Touch-me-not | South America | TER; FOR | W | +++ | NG | HI | 1, 5, 7, 8 | |
| Pod | Lamiaceae | Xylica doliabiforimis | Pignado | Myanmar, India | TER; FOR | Ti | ++ | P | I | 7, 12 | |
| Pod | Lamiaceae | Hyptis suaveolens | Pignado | Myanmar, India | TER; FOR | Ti | ++ | P | I | 7, 8, 11, 12 | |
| Pod | Limnocharitaceae | Limnocharis flava | Yellow burhead | South America | AQU | W | +++ | NG | HI | 1 | |
| Pod | Malvaceae | Triumfetta rhomboideae | Diamond burback | China | TER; AGR | W | ++ | NG | I | 6 | |
| Pod | Malvaceae | Urena lobata | Caesar weed | South America, Africa | TER; FOR | W | ++ | NG | HI | 7 | |
| Pod | Melastomataceae | Melastoma malabathricum | Indian rhododendron | Australia | TER; FOR | W | ++ | NG | I | 7, 8 | |
| Pod | Meliaceae | Swietenia macrophylla | Mahogany | South America | TER; FOR | Ti | +++ | P | I | 7, 11, 12 | |
| Pod | Myrtaceae | Eucalyptus brashiana | Eucalyptus | Australia | TER; FOR | Ti | ++ | P | PI | 12 | |
| Pod | Myrtaceae | Eucalyptus camaldulensis | Eucalyptus | Australia | TER; FOR | Ti | ++ | P | I | 4, 5, 7, 8, 11, 12 | |
| Pod | Onagraceae | Ludwigia adscendens | Water primrose | South America | AQU | W | +++ | NG | I | 4, 5, 6 | |
| Pod | Papaveraceae | Argemone mexicana | Mexican prickly poppy | Tropical America | TER; AGR | O, W | + | NG | I | 8 | |
| Pod | Pinaceae | Pinus caribaea | Caribbean pine | South America | TER; FOR | Ti | ++ | P | I | 11, 12 | |
| Pod | Pinaceae | Pinus oocarpa | Pine | South America | TER; FOR | Ti | + | P | PI | 11, 12 | |
| Pod | Poaceae | Cynodon dactylon | Bermuda grass | Africa | TER; AGR | W | +++ | NG | HI | 6 | |
| Pod | Polygonaceae | Persicaria hydropiper | Water pepper | North America | AQU | W | ++ | NG | HI | 48 | |
| Pod | Polygonaceae | Eichhornia crassipes | Water hyacinth | North America | AQU | W | +++ | NG | HI | 1, 4, 9 | |
| Pod | Polygonaceae | Solanaceae | Giant salvinia | South America | AQU | W | +++ | NG | HI | 1, 11 | 4, 5 |
| Pod | Polygonaceae | Cestrum diurnum | Day blooming cestrum | South America | AQU | W | +++ | NG | HI | 4, 5, 7, 8, 9, 11 | |

Table key.
Habitat type: TER – terrestrial, AQU – aquatic, AGR – agricultural, FOR – forest, WF – waste and fallow land.
Usage: F – food, Fo – fodder, Fu – fuel, Ni – nitrogen fixation, O – ornamental, P – pest, W – weed, T – timber.
Occurrence: +++ – common, + – moderately common, – rare.
Mode of regeneration: C – cultivated, NG – naturally growing; P – planted.
Level of invasiveness: HI – highly invasive, I – invasive, PI – potentially invasive.
Source(s): 1 – GISD (2019), 2 – Barua et al. (2001), 3 – Galib (2015), 4 – Hossain (2009), 5 – Hossain and Pasha (2001), 6 – Rahman and Roy (2014), 7 – Uddin et al. (2013), 8 – Khan et al. (2011), 9 – Akter and Zuberi (2009), 10 – Biswas et al. (2007), 11 – Mukul et al. (2006), 12 – Zabala (1990).

When considering their current usage, the majority (53.6%) of the identified IAS were reported as pests or weeds, and therefore, were most likely to have been unintentionally introduced into the country. Few species such as Eichhornia crassipes and L. camara, were introduced during the colonial period as ornamental plants. Other species, like Tectona grandis, Falcataria moluccana, and Xylica doliabiforimis were introduced from neighboring countries during the colonial period as part of large-scale timber plantation programs implemented following clearcutting of native vegetation for timber extraction (Hossain,
Species like *Leucaena leucocephala* were also introduced before Bangladesh's independence mainly to provide fodder and to aid nitrogen fixation in soils (Hossain, 2009).

A majority of the identified IAS, including fishes, that were introduced after Bangladesh's independence, were introduced largely to supplement the country's food supplies (18.9%) and timber production (14.5%). Fig. 6 shows the number of identified IAS in Bangladesh by their purpose and timing of introduction (i.e. pre- or post-independence).

### 3.3. Impacts of invasive alien species on ecosystems and people

The majority (56.5%) of the identified IAS are common in different ecosystems in Bangladesh (Fig. 7). When considering their level of invasiveness in the country, most (51.1%) of the species were found to be highly invasive followed by 36.2% invasive and 8.7% potentially invasive (Fig. 8).

It was also found that most (75.4%) of the identified IAS in Bangladesh can regenerate naturally, while the remainder (21.7%) are either planted or cultivated in the country (Fig. 9). Some of the common timber species, such as *Acacia* sp.,
Eucalyptus sp., Pinus sp., and Swietenia sp., that have been widely used in plantation programs usually do not regenerate naturally although in their native range they are famous for their natural regeneration capacity via wildings.

Fig. 10 shows the identified IAS’s major impacts on ecosystems and people in Bangladesh. Economic losses due to IAS are mainly incurred by their management and eradication (e.g. Eichhornia crassipes), and losses in agricultural yields, while environmental impacts include losses in productivity of native species attributed by competition for food and shelter from IAS, and changes in ecosystem integrity. Some of the identified IAS (e.g. Acacia sp.) are also considered to pose health hazards, like asthma and allergies, during their flowering season.

4. Discussion

4.1. Invasive alien species in Bangladesh

There are no particular set of traits that clearly separates highly invasive from less or non-invasive species (Richardson et al., 2015). Consequently, it is difficult to separate invasive from non-invasive species in Bangladesh (Mukul et al., 2006).
Perhaps the first widely introduced IAS in Bangladesh was *Eichhornia crassipes* which was introduced from Brazil during the British colonial period (Barua et al., 2001). The deliberate preferences of government’s related sector’s (i.e. agriculture, fisheries and forestry) for fast-growing, high-yielding cultivars over native species led to the introduction of some potentially harmful exotic species in the country (Hossain, 2009). An initial list of IAS in Bangladesh prepared by Zabala (1990) included nine exotic plant species (i.e. *Acacia auriculiformis*, *A. mangium*, *Albizia falcataria*, *Dalbergia siso*, *Eucalyptus camaldulensis*, *E. brassiana*, *Leucaena leucocephala*, *Swietenia macrophylla*, *S. mahagoni*), although not all of these fulfill the criteria of IAS (Akter and Zuberi, 2009). The introduction of *Acacia* sp. and *Eucalyptus* sp. from Australia during the 1980s created several controversies as species belonging to these two genera are proven to be rivals to the endemic flora and found to be
environmentally unfriendly in regions with longer plantation histories (Richardson et al., 2015; Hossain and Hoque, 2013; Ameen, 1999).

There are believed to be many pests and microorganisms which have been introduced into Bangladesh during agricultural trade that remain largely unknown (Zuberi and Akter, 2007; Mamun et al., 1987). Many of the invasive fish species including some ornamental and game fish were brought to the country during the 1990s (Galib and Mohsin, 2010). Currently, the most disastrous invasive alien fish species in the country are — *Clarias gariepinus*, *Pangasius sutchi*, *Pangasius sanitwongsei*, *Tilapia mossambica* and *Oreochromis niloticus* (Rahman, 1997). All these species are recognised as the world’s worst invasive alien species (Lowe et al., 2000). In recent years, unregulated wildlife trade and imports, and a growing urban market for pet wildlife, has also caused the introduction of some potentially invasive fauna into the country’s ecosystem.

4.2. Threats from invasive alien species in Bangladesh

Although economic losses due to IAS in the agricultural sector in Bangladesh is well documented, a reliable estimate of this loss is still unavailable for the country (Barua et al., 2001). In forest ecosystems, fast-growing exotic species such as *Acacia* sp., *Eucalyptus* sp. and *L. leucocephala* compete with native species for soil water and nutrients (Hossain and Hoque, 2013; Zabala, 1990). Many of these species are also reported to possess an allelopathic effect which suppresses the development of undergrowth (see — Mahmud et al., 2018; Hossain et al., 2016; Al-Mamun et al., 2013; Ahmed et al., 2008b, 2007). Other species such as *Eichhornia crassipes* and *Salvinia molesta* are responsible for large-scale obstruction of the navigation system in the country’s inland water bodies, while also negatively affecting fish production (Afrin et al., 2010; Islam et al., 2003). Some of the IAS, although providing certain benefits like food, timber, fuelwood, nitrogen fixation in soil and possessing therapeutic uses, have environmental costs that in most cases exceed their benefits (see — Rahman and Roy, 2014; Khan et al., 2011; Rahman et al., 2010; Rana and Akhter, 2010; Rana et al., 2010; Mukul et al., 2006; Biswas, 2003; Islam et al., 1999).

The predatory habit of most of the introduced fish species in Bangladesh is well recognised. Although others are not predatory, their fecundity and growth rate are extremely high (Galib, 2015; Barua et al., 2001). They also compete with native fish species for food. The exotic fish species *Clarias gariepinus* feeds on native fish species, thereby causing their depletion in inland water bodies (Galib and Mohsin, 2010). The feeding habit of some of the introduced carp species also caused pond bank erosion, increased turbidity, elevated nutrient concentrations, and alteration to physical and chemical conditions of water. These impacts have ecological consequences, such as increased phytoplankton density in response to elevated nutrient levels (Wittenberg and Cock, 2001).

The impacts of IAS on a country’s genetic pool is also significant. Invasive alien species may hybridize with native species, thus altering genetic diversity and integrity of native species (Vila et al., 2011; Wittenberg and Cock, 2001). Exotic species are also common pathways for the transmission of diseases and pathogens. For example, the invasive *Argulus* sp. has been introduced with the introduction of carp into Bangladesh (Islam et al., 2003). It is also widely believed that the White spot syndrome virus of shrimp, which has caused a devastating fall in shrimp production and export from Bangladesh, was introduced via fish imported from neighboring countries (Islam et al., 2003).

Fig. 8. Numbers and percentages of identified IAS in Bangladesh by their level of invasiveness.
5. Concluding remarks

As a signatory to the United Nations Convention on Biological Diversity (UN CBD), biodiversity conservation is a national priority for Bangladesh. Nevertheless, a comprehensive assessment and framework for identifying IAS is still lacking in the country. The country’s extensive borders with neighboring countries (i.e. India and Myanmar) make it highly vulnerable to foreign species introduction. Enforcement of existing safeguard mechanisms, such as appropriate quarantine measures when importing any exotic species into the country, is also weak. The government should be cautious when introducing new species in the country, and ensure clear and effective quarantine regulations are in place and are adequately enforced. Appropriate policies and regulations must be developed to facilitate the control of IAS in the country. A statutory body consisting of local experts alongside comprehensible standards and procedures for the introduction, monitoring and management of alien species in the country’s agriculture, forestry and fisheries sectors is also essential.
Whilst mechanical, chemical, and biological controls are the most widely used approaches for controlling IAS, they require skilled manpower, technology, and expertise, and can be extremely costly and labor intensive. Preventive measures, therefore, should be the highest priority of the government. Community awareness and local peoples’ involvement with relevant stakeholders should be advocated for managing IAS in the different land-uses and ecosystems throughout Bangladesh. Community-based vigilance and monitoring of known pathways for IAS introductions should also be undertaken. In the case of transboundary landscapes and water bodies, regional cooperation must be sought for the effective management of IAS in Bangladesh. Improved capacity building of government staff involved in quarantine and border control operations is also needed.

**Declaration of competing interest**

The authors declare no conflict of interest.

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**Appendix A. Supplementary data**

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