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Applicability of "Invasive Species Assessment Protocol" in Bangladesh

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DECLARATION

I, Md. Shiddikur Rahman, declare that this project thesis is the result of my own research work and it has not been submitted or accepted for any other degree in any university.

I, hereby, give consent for my thesis, if accepted, to be available for photocopying and for interlibrary loans, and for the title and summary to be made available to outside organizations.

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DEDICATED TO

MY BELOVED PARENTS

&

SIBLINGS

APPROVAL

The style and format of the project thesis submitted to forestry and wood technology Discipline, Khulna University, Khulna, Bangladesh, in partial fulfillment of the requirements for the 4-year's professional BSc. (Hons.) degree in Forestry has been approved.

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ABSTRACT

A comprehensive review was done by using the invasive species assessment protocol to make a contribution to prepare a national list of invasive alien plants in Bangladesh. We have identified the invasive trees from existing journals and categorized them by applying the protocol and made the justification for its applicability. Initially, twenty-three tree species were listed as invasive and we could able to rank seventeen species. Six species were omitted of which five native and no record were found for the other as the protocol only deals with the non-natives. After I-Rank assessment, we have got six species such as *Acacia auriculiformis*, *Dalbergia sissoo*, *Eucalyptus camaldulensis*, *Eucalyptus grandis*, *Leucaena leucocephala*, *Pinus caribaea* in high rank, *Xylia dolabriformis* in medium rank, four species in high to medium rank, four species in medium to low rank and two species in high to low rank. This assessment reveals which species pose the serious threat to biodiversity and which species should be given priority in the plantation by individuals or government. Last but not least, it provides a baseline that the protocol can be applied in creating a national list of invasive alien plants in our country.

Keywords: Invasive alien species, Non-native species, Invasive species assessment protocol, I-Rank, Biodiversity.

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CHAPTER ONE: INTRODUCTION

1. Introduction

1.1 Background and justification of the study

Biological invasion is regarded as one of the most important components of global change that poses serious threats to the conservation of native ecosystems and biodiversity all over the world (D'Antonio & Vitousek, 1992., Dukes & Mooney, 1999., Lonsdale 1999., Mack et al., 2000., Fine, 2002., Mooney & Hobbs, 2002., Naylor, 2002., Seabloom et al., 2006). During the last 100 years, human activities, especially international travel and trade, have overcome oceanic and others natural barriers for world's biota. These anthropogenic vectors are accelerating the rate of invasion by invasive alien species which cause native species extinction (Dukes & Mooney, 1999., Lonsdale, 1999., Gurevitch & Padilla 2004). Biogeographically, Bangladesh is rich in biodiversity and located at the crossroads of the Indo-Himalayan and Indo-Chinese sub-regions under the Oriental region. Thus, our country acts as an important merging and sharing habitat, land bridge and biological corridors of the flora and fauna between these sub-regions (MoE, 2015). But current biodiversity status is under stress. The introduction and rapid spread of invasive alien plants and animals are predominantly responsible for this (NBSAP, 2006) and they were historically introduced to their higher productivity and income potential. Early introductions were linked with the import of exotic goods from almost every nation of Asia. It is believed that many invasive alien species were indiscriminately introduced from India with floodwaters and rapidly spread to the wetlands in Bangladesh. Unfortunately, the likely adverse effects of introducing those species were not considered and quarantine measures during import of alien species were weak, and as a result, they were introduced into the country without proper documentation. In spite of the absence of studies, it is believed that the increasing number of alien species are causing significant economic, environmental and health hazards in Bangladesh although some have become naturalized (Pallewatta, 2003). Currently, few studies are found regarding the negative impacts of the introduction of invasive alien species, particularly plants and no complete list of those plants are available. Several authorities and experts have developed a few lists of invasive plants by using different methods or parameters (Barua et al., 2001., Hossain & Pasha, 2001., Zabala, 1990., Akter & Zuberi, 2009., Biswas et al., 2007., Islam et al., 2003., Rana & Akhter, 2010., Mukul et al., 2006., Khan et al., 2011., Rahman & Roy, 2014). There are no records of the introduction

of a number of plant species. But, the deliberate preferences of fast growing high yielding cultivars eroded some of the native species and the genetic resources abruptly. More than 300 exotic plant species are supposed to either growing in the wild or cultivated as an economic crop in Bangladesh (Hossain and Pasha 2001). Of them, the herbaceous and lianas are the dominant exotics followed by trees and shrubs.

It is now an urgent need to create a national list of invasive alien plants with their prevailing harmful consequences to local biodiversity. But we have no such method or model to do so. "Invasive Species Assessment Protocol" can be an alternative and effective solution to this problem. It is a tool for assessing, categorizing, and listing non-native invasive vascular plants according to their impact on native species and natural biodiversity which can be more useful to policy makers, researchers, regulators, consumers, and commercial interests such as the nursery industry as well as for agencies, organizations, and individuals engaged in protecting biodiversity.

In this work, we are just trying to apply this protocol to those invasive tree species mentioned in the existing literatures to categorize and list them on the basis of negative impacts to biodiversity as high, medium, low and insignificant and finally, we will identify whether this protocol can be used in **categorizing and listing all the non-native plants** including trees, herbs, shrubs, climbers or weeds found in Bangladesh which will provide a guideline to the decision-makers about the next steps for the management of those species.

1.2 Objectives of the study

- To identify and categorize the invasive tree species in Bangladesh with the help of the "Invasive species assessment protocol".

- To find out the applicability of the protocol in preparing a national list of invasive alien plant species.

CHAPTER TWO: LITERATURE REVIEW

2. Literature review

2.1 Definitions of related terms

2.1.1 Invasion and Invasion Ecology

In the Oxford English Dictionary, the word "invasion" means "the act of an army entering another country by force in order to take control of it". Legally this term means "encroachment upon the property, rights, privacy, etc., of anyone".

In the plant ecology, the terminology "invasion" is normally applied to those conditions where the distribution and abundance of plants change for human activities. The terms migration, spread, range expansion, or range extension are used for other conditions such as after the retreat of glaciations (Pyšek et al., 2004).

The human-mediated introduction of organisms into areas outside of their potential ranges (as defined by natural dispersal and biogeographic barriers) is a distinct branch of science termed "invasion ecology" (Davis, 2009., Lockwood et al., 2009). It was first developed by Elton (1958) as a means to embed life histories and population ecologies of invasive species within the context of conservation and management. Additional early efforts (Laycock, 1966) established to the lay public the extensive economic and conservation harm that can be produced by such introductions. However, as a discipline, invasion ecology is not without controversy. Much of it is due to a clock that has oscillated between slower and faster manifestations (Douglas et al., 2015).

2.1.2 Alien, Invasive and Invasive Alien Species

Alien species is a species that has been intentionally or unintentionally introduced to a location, area, or region where it does not occur naturally.

According to the Convention on Biological Diversity (CBD) "Alien species refers to a species, subspecies or lower taxon, introduced outside its natural past or present distribution; including any

part, gametes, seeds, eggs, or propagules of such species that might survive and subsequently reproduce."

On the other hand, Invasive Species Advisory Committee (ISAC) defined invasive species as "Invasive species are those that are not native to the ecosystem under consideration and that cause or are likely to cause economic or environmental harm or harm to human, animal, or plant health. Plant and animal species under domestication or cultivation and under human control are not invasive species (Beck et al., 2009)."

The term "invasive" includes alien species as well as widespread species that have negative effects on the recipient ecosystem (Davis & Thompson, 2000., Mack et al., 2000).

An invasive species may be invasive in one part of the country, but not in another. Various terms are found in the literature regarding invasive species including non-indigenous, aliens, naturalized species, immigrants, exotics, weeds, pests, colonizer, invaders, exotics, transformers, neophytes, introduced species and bioterrorists (Jarvis, 1979., Heywood, 1989., Dukes & Mooney, 1999., Lonsdale, 1999., Williamson, 1999., Brabec & Pysek, 2000., Meyerson & Reaser, 2003., Colautti & MacIsaac, 2004., Meyerson et al., 2009).

Invasive alien species (IAS) refers to an alien species that has established and spread, and which causes, or has the potential to cause, harm to the environment, economics, or human health.

There are various versions of the IAS definition.

An IAS is an alien species whose establishment and spread threaten ecosystems, habitats or species with economic or environmental harm (CBD).

An IAS is an alien species which becomes established in natural or semi-natural ecosystems or habitats, is an agent of change, and threatens native biological diversity (IUCN, 2000).

2.2 Biodiversity Conservation and Invasive Alien Species

Biodiversity conservation is a multidimensional concerted effort to conserve a species at genetic, species and ecosystem levels. Simply it is the process by which any or all organisms of the ecosystem is protected in or outside ecosystem with several strategies (Miller, 2005). Nowadays biodiversity conservation has become a national priority. The role of invasive alien species in relation to biodiversity loss is significant and it has been well documented (Mack et al., 2000., Hobbs, 2000., Polley et al., 1994., Czech & Krausman, 1997., Wilcove & Chen, 1998., di Castri, 1998).

2.3 Predicting Species Invasiveness

It is difficult to predict invasiveness of a species because it is hard to identify the characteristics that distinguish invasive from harmless alien species. However, there are some guidelines. Current best predictors for identifying which introductions are most likely to establish, spread and cause harm are broken into two groups: the "potential" of the organism and the "susceptibility" of the ecosystem (ISSG, 2005).

2.4 Approaches to define invasive species

Several approaches are found in the literature to define invasive species. Davis and Thompson (2000) recognized eight types of colonizers and recommended that the term invader can be used for only two types (**Figure 1**).

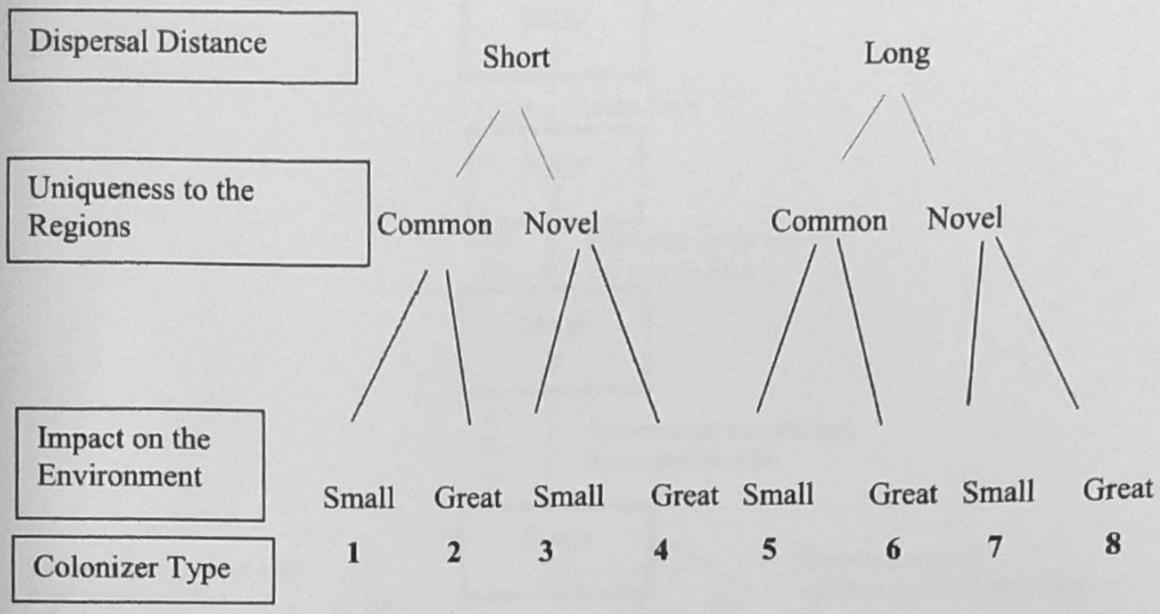

Figure 1: The eight colonizer types proposed by Davis and Thompson (2000)

Types 1, 2, 5 and 6 can be considered successional colonizers; types 3 and 7 can be considered novel, non-invasive colonizers and types 4 and 8 can be considered novel, invasive colonizers.

Colautti and MacIsaac (2004) proposed a neutral model (**Figure 2**) in which, a non-indigenous potential invader passes through a series of filters that may preclude transition to subsequent stages. The three classes of determinants affect the probability that a potential invader will pass through each filter: (A) propagule pressure; (B) physicochemical requirements of the potential invader; and (C) community interactions. Determinants may positively (+) or negatively (–) affect the number of propagules that successfully pass through each filter.

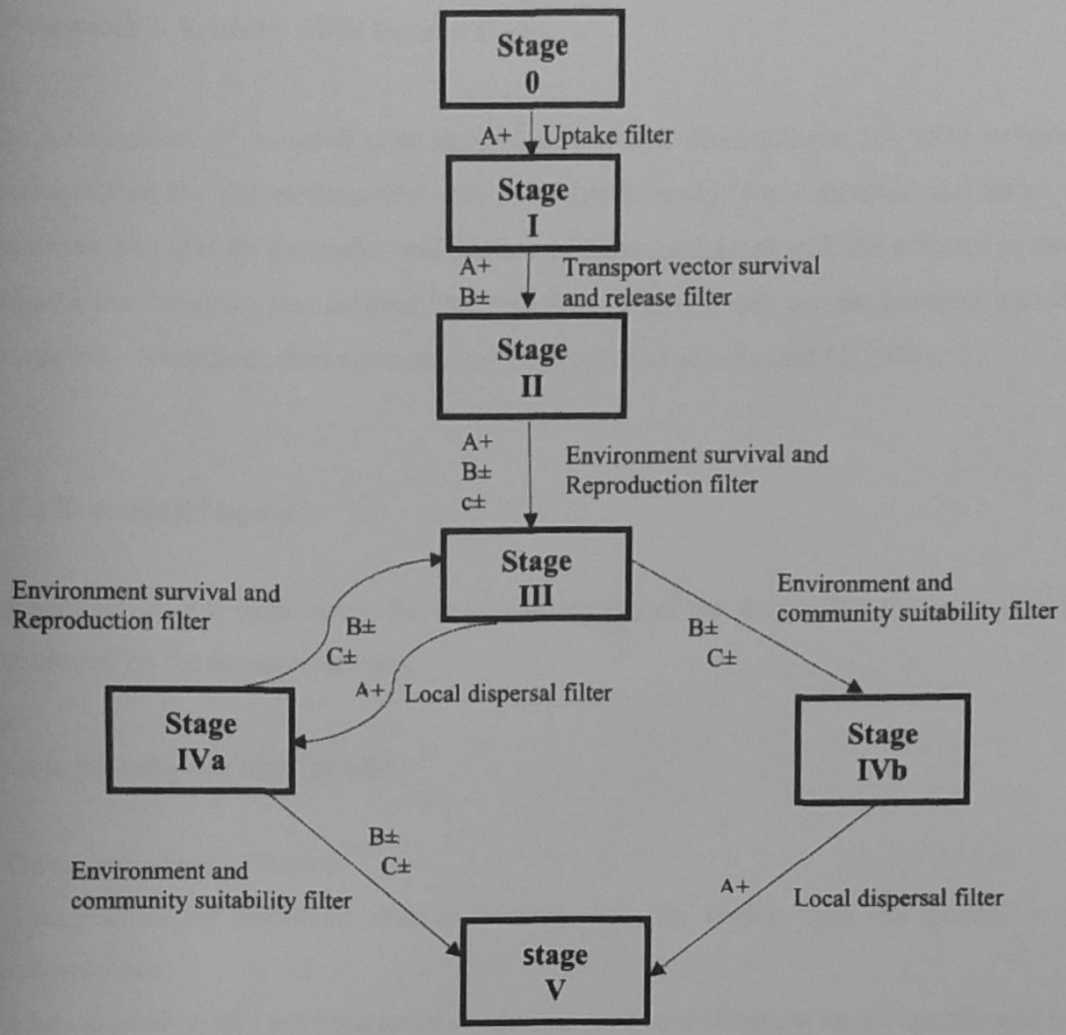

Figure 2: A neutral model or framework for defining operationally important terms in invasion studies (after Colautti & MacIsaac, 2004).

Under this framework, a non-indigenous species may be-

- localized and numerically rare (stageIII)
- widespread but rare (stage IVa)
- localized but dominant (stage IVb)
- widespread and dominant (stage V)

Stage **Iva** and **stage V** indicate invasive as they are widespread

2.5 Impacts of Invasive Alien Species (IAS)

The introduction of invasive alien species into a new environment can have serious negative consequences for the environment and local biodiversity, for industries and users of natural resources, and also for the health and welfare of those associated with the affected systems. While impacts can be direct and indirect, the principal consequences can be grouped into three main categories - ecological, economic and public health and society (ISSG, 2005).

2.5.1 Ecological Impact

Ecological impacts occur when the local biodiversity of the area and/or the ecological processes are altered by the invasive species.

Ecological impacts may include:

- Direct predation/herbivory.
- Competition for resources, such as nesting sites (for birds), light (for plants) or preferred food/nutrients.
- Altering habitats and environmental conditions such as shading out native species and freshwater systems, increasing erosion or changing natural fire regimes.
- Spreading pathogens and parasites.
- Disturbing ecological processes and thereby facilitating invasion by other alien species.
- Altering of the food web and nutrient cycles.
- Synergies with other IAS, such as degrading the environment so that further invasions are facilitated.

2.5.2 Economic Impact

Invasive species may cause major economic losses to society, whether in the form of direct economic impacts, such as loss of agricultural or fishery production, or secondary economic impacts caused by human health issues.

Economic impacts may include:

A) Direct costs:

- Direct loss of crops to introduced crop pests.
- Spoiling of produce, rendering products unsuitable for consumption.
- Loss of export earnings due to prohibitions on exporting products infected by IAS.
- Reductions in agricultural production due to the displacement of pasture by unpalatable grasses and woody species, and/or through habitat/environmental changes caused by the invading species.
- Impacts on fisheries and aquaculture (including the closure of fisheries or aquaculture facilities).
- Secondary economic impacts from human health issues associated with introduced pathogens and toxic species, including increased monitoring, testing, diagnostic and treatment costs, and loss of social productivity due to illness and death in affected people.
- Loss of tourism revenues due to disease epidemics (e.g. the SARS outbreak in China in 2003).
- Costs of producing and using chemicals and machines to deal with IAS.

B) Indirect costs:

- Degradation of ecosystem services.
- Loss of human productivity due to time and resources allocated to dealing with IAS.
- Damage to infrastructure due to ecosystem changes.
- The costs of responding to the problem, including research and development, monitoring, education, communication, regulation, compliance, management, mitigation, and control costs and restoration activities.

The costs to non-economic sectors (for instance, the natural environment and societal or cultural values) of IAS, while not easily measurable in monetary terms are also significant.

2.5.3 Public Health and Society

The full costs of invasions also include the social and health impacts of alien invasive species on humans.

Infectious disease agents may themselves be IAS or may be introduced by IAS vectors (e.g. introduced mosquitoes carrying malaria). Diseases can affect the movement of people and limit tourists to an area. This was demonstrated by the Severe Acute Respiratory Syndrome (SARS) outbreak in 2003 where there was a worldwide downturn in tourism (ISSG, 2005).

Forest workers, as part of their jobs, and people living in and around forests are more exposed to alien invasive species such as the reservoirs and hosts of many emerging infectious diseases. Examples of such diseases include Lyme disease, human immunodeficiency virus (HIV), Ebola and Marburg hemorrhagic fevers, malaria, yellow fever, leishmaniosis, trypanosomiasis, and Kyasanur forest disease. People living in and around invaded forest areas may also suffer allergic or other negative reactions to the alien invasive species themselves or to the measures used to control them such as chemical and biological pesticides (Moore, 2005).

2.6 Invasive Alien Species and Bangladesh

According to **Bangladesh's Fifth National Report to the CBD (MoEF, 2015)**, the introduction of invasive alien species is the main threat to biodiversity after the land-use change and habitat destruction.

In Bangladesh introduction of alien invasive species of flora and fauna were deliberate primarily in order to increase productivity to support the needs of a huge population. Very scarce information is available about the invasive alien species in Bangladesh and their impacts on the ecosystem and the native species (Zabala, 1990., Barua et al., 2001., Hossain and Pasha, 2001., Islam et al., 2003., Biswas et al., 2007., Akter & Zuberi, 2009).

In 1978 and onwards, extensive trials of *Eucalyptus* and *Acacia* species started to find out the very fast growing exotic species for some difficult sites. Later on, a trend of planting *Eucalyptus* and *Acacia* were getting preferences in plantation programmes. But a Government ban on *Eucalyptus* prevented its large-scale plantation programmes. However, individual interest on *Eucalyptus* is still observed in planting around homesteads and marginal lands (Hossain & Hoque, 2013).

2.7 Measures Taken to Control Invasive Alien Species in Bangladesh

Though Bangladesh is yet to undertake effective and systematic measures to prevent the introduction of, control or eradicate invasive alien species threatening ecosystems, habitats or species, there are some independent initiatives by the Government NGOs and International organization like IUCN for eradication or control of alien species in Bangladesh. The Government has already implemented some events regarding control of invasive alien species in Bangladesh. With the development of the NBSAP-National Biodiversity Strategy and Action Plan (MoEF, 2006), Bangladesh has progressed remarkably towards fulfilling the global commitment of the country to the CBD. Strategies and actions for taking measures on the invasive alien species in Bangladesh are incorporated in the NBSAP.

The Progress of Implementing the National Biodiversity Strategy and Action Plan (2010-2015) regarding the invasive alien species is as follows:

NBSAP Strategy	**Actions in NBSAP**	**Activities reported in the Fourth National Report (MoEF, 2010)**	**Accomplishment during the Fifth National Report (2010-15)**
National measures and standards to deal with invasive alien species and genetically modified organisms.	***Short term (0- 3 years)*** • Develop national management plans for control and eradication of invasive alien species. •Support capacity building on identification of invasive species and genetically modified organisms. • Develop a national biosafety framework.	□ Plant Quarantine system with limited capacity is in place to control IAS; □ NBF has been developed in 2006 and biosafety rules have been drafted in compliance with Cartagena Protocol on Biosafety;	□ DoF has addressed the issues of invasive fishes like African Catfish and Piranha. □ Implementation of Biosafety Framework: local, regional and international developments and cooperation/dialogues, initiatives have made slow progress.

	• Locally monitor and prevent the release of IAS and hybrids in aquatic ecosystems. ***Medium term (4-7 years)*** •Develop capacity building tools and methods for local communities to deal with identification, management, and control of invasive species and GMOs. • Build awareness of biosafety and biopiracy issues among local communities and within the Customs Service ***Long term (8-10 years)*** • Support establishment of monitoring systems for addressing issues of regional and international trade and their impact on movement and/or introduction of invasive species and genetically modified organisms. • Support economic and social impact studies on use of genetically modified organisms and alien species. • Encourage regional	□ Biosafety Clearing House (BCH) has been established and got connected with central portal operated by SCBD; □ Implementation project on NBF is underway to be initiated; □ Bangladesh is participating in regional dialogue in managing IAS and GMOs	□ Various committees are working on the checkpoints.

	dialogue on sharing of expertise and resources in the management of IAS and GMOs.		

2.8 Invasive Species Assessment Protocol

The protocol was developed by The Nature Conservancy, NatureServe, and the U.S. National Park Service in cooperation with the Plant Conservation Alliance's Alien Plant Working Group. Early input was provided by The Nature Conservancy staffs. Invasive Species Assessment Protocol is a tool for assessing, categorizing and listing non-native invasive vascular plants according to their impact on native species and natural biodiversity in a large geographical area such as a nation, state, province, or ecological region. This protocol is designed to make the process of assessing and listing invasive plants objective and systematic and to incorporate scientific documentation of the information used to determine each species' rank. Species (or infraspecific taxa, as appropriate) are assessed one at a time for a specified "region of interest" to determine an Invasive Species Impact Rank (I-Rank) categorizing the species' negative impact on natural biodiversity within that region as high, medium, low and insignificant.

The style and organization of this protocol draw heavily on NatureServe's long-established methodology for assessing conservation significance of various native plant or animal species, used by natural heritage programs and conservation data centers in all the U.S. states and Canadian provinces, as well as several Latin American or Caribbean nations. The protocol's availability and its recent implementation within NatureServe's Biotics information-management system extend NatureServe's species assessment methodology to non-native as well as native species.

Several years ago, The Nature Conservancy identified the need for an analytically developed, scientifically based United States national list of non-native plants that negatively impact native biodiversity. Despite the increasing interest in invasive species and their environmental and

economic impacts, no such list existed. The U.S. Department of Agriculture and many state and county agriculture agencies maintain official noxious weed lists but the majority include only species that negatively affect agricultural production or have other negative impacts on human health or the economy. For this reason, a variety of government agencies and private conservation organizations have created separate lists of the non-native plant species regarded as significant threats to biodiversity conservation.

Unfortunately, for many of the existing lists, there is no documentation of the factors used to determine which species were included and how they were placed into different categories. Careful examination of these different lists and consultation with the people who created them reveals that the factors used as the basis for making decisions are similar in most cases but that there are some significant differences. This makes comparisons between lists difficult.

So, first the existing protocols for listing invasive plants were assembled and evaluated for intended use, intended scale of application, and the specific evaluated factors and finally, a new protocol was developed named **"Invasive Species Assessment Protocol"** that would use types of information that are available for most plant species and would distinguish between species that have high, medium, low or insignificant negative impacts on biodiversity.

An early version of the protocol was briefly described in Randall et al. (1996) and an intermediate version was described and presented in full by Randall et al. (2001). The protocol has gone through several subsequent rounds of testing, review, and revision, resulting in the final version.

As it is a clearly explained, consistent protocol, it will make the listing process more analytic, transparent, equitable, and authoritative. National, state, and regional lists produced with such a protocol will be more useful to researchers, regulators, consumers, and commercial interests such as the nursery industry as well as for agencies, organizations, and individuals engaged in protecting biodiversity.

The NatureServe is now using this protocol to assess the estimated 3,500 non-native vascular plant species that are established in the United States to create a national list prioritized by the negative impact on biodiversity. Over 500 completed species assessments are available through

NatureServe Explorer (http://www.natureserve.org/explorer/). The protocol and instructions for using it are freely available on the Internet at http://www.natureserve.org/getData/ plantData.jsp.

This freely available protocol will be useful for creating other national, state, provincial, and regional lists. It is believed that subjecting this protocol to greater scrutiny may help lead to the development of an improved, more objective and accurate version, particularly as detailed information on the impacts, distribution, and rates of spread of many more invasive species based on experiments and field observations becomes available.

This protocol has several limitations. It is not intended for use in prediction and risk analyses to identify likely invaders among species that have been proposed for importation but are not yet present in the area. It is also not intended for use in developing management priorities for a specific conservation area where impacts on specific populations of rare native species or community types would have to be considered. It is not useful for assessing priorities among invasive species for agricultural systems, ranchlands, production forests, or horticultural settings such as yards and urban parks because it does not assess impacts on these systems.

CHAPTER THREE: MATERIALS AND METHODS

3. Materials and Methods

This study is mainly based on secondary sources. Available published information about invasive species in Bangladesh were collected, categorized and assessed using the invasive species assessment protocol.

3.1 Making a list of invasive alien tree species

Firstly, an initial list of invasive tree species in Bangladesh was prepared after reviewing all the available published papers and books relating to the invasive species and we got twenty-three invasive tree species (Table 3). Several keywords like "Invasive alien species", "Alien species", "Invasive species", "Exotic species", "Bangladesh" were searched in google and google scholars to find out the invasive trees of Bangladesh.

3.2 Applying the "Invasive Species Assessment Protocol" to categorize those species

Then by utilizing the Invasive Species Assessment Protocol, we categorized the invasive alien species into four categories: high, medium, low, or insignificant negative impacts to native biodiversity.

3.2.1 Description of the protocol

The intention of the protocol is to assess the impact on biodiversity of those species which are non-native in a specific area or region of interest, or at least non-native in some portion of the region different from their local range.

It comprises 2 initial screening questions (Yes/No) and 20 questions that constitute the main frame of the protocol. The protocol score-sheet provides instructions for allocating points to each answer and for counting the points to determine a subrank for each of the four sections with an overall

Invasive Species Impact Rank (called an ''I-Rank'') for respective species. I-Ranks vary from High to Insignificant as follows:

High: Species with the severe threat to native species and ecological communities.
Medium: Species with the moderate threat to native species and ecological communities.
Low: Species with the significant but comparatively low threat to native species and ecological communities.
Insignificant: Species with the insignificant threat to native species and ecological communities.

3.2.1.1 Screening Questions

S-1: Is it non-native established outside of the cultivation?

Yes. Proceed to screening question S-2, below.
No. STOP. The Invasive Species Assessment Protocol is not applicable to this species.

Enter 'Not Applicable' as the Invasive Species Impact Rank (I-Rank), summarize reasons in the I-Rank Reasons Summary, and cite at least one information source.

S-2: Does it occur in conservation areas?

Yes. Proceed to the assessment (20 questions), below.
No. STOP. This species is an insignificant threat to natural biodiversity in the region of interest.

Enter 'Insignificant' as the Invasive Species Impact Rank (I-Rank), summarize reasons in the I-Rank Reasons Summary, and cite at least one information source.

3.2.1.2 Assessment Questions

When both the screening questions provide the answer 'yes', then the 20 assessment questions are answered(Appendix2) that are grouped into four sections.

Section I. Ecological impact (five questions, 50% of I-Rank score)

This section is grounded on the basis that species with the highest negative impacts on native plant, animal, and other species populations, ecological communities, and ecosystems usually cause the most severe problems, mainly if they change ecosystem processes, or harm rare native species, keystone species, or communities of conservation significance. Here, the questions evaluate the species' overall impacts on natural biodiversity on a rough per-unit-area basis. Impacts should be assessed for areas with abundances (cover, density, frequency, etc.) commonly seen in the field. The questions are organized in hierarchical order. In general, species that have strong impacts on ecosystem processes or parameters will also have strong impacts on many lower scales, including community composition and structure and native species populations. Effects of other non-native species appear at only lower scales, and for some, the impacts are not noticeable. The last question in this section focuses on the conservation significance of the species and ecological communities impacted by the non-native species under assessment.

Section II. Current distribution and abundance (four questions; 25% of I-Rank score)

This section is grounded on the basis that if the range and abundance of a species in a region and invaded ecological regions are higher, then the overall damage that the species can cause will be greater. One question in this section is intended to determine the rough proportion of the range occupied where the species under evaluation has major impacts, since some non-native species are established over wide areas but are recognized or supposed to cause harm to biodiversity merely in part of the whole area where they are established, or only in certain habitats.

Section III. Trend in distribution and abundance (seven questions; 15% of I-Rank score)

This section is grounded on the basis that species with a high potential for further spread have the potential to cause greater damage, particularly if they are likely to spread to distant but currently uninfested portions of the region of interest. Here, the questions evaluate the likelihood and rate at which the species (if not controlled) will spread to new areas and/or increase in abundance within areas it already occupies. Assessments of the species' current range, its probable potential range in the region, and its current spreading rate help to answer questions in this section.

Section IV. Management difficulty (four questions; 10% of I-Rank score)

This section is grounded on the basis that a species that is difficult to manage (control or prevent from spreading) will have a higher chance of causing substantial damage because it is more likely to persist and spread. Here, the questions evaluate the difficulty of control, the accessibility of invaded locations where it frightens natural diversity, and the likelihood that recognized control measures will cause collateral damage to native species.

3.2.1.3 Answering the Questions

The individual question contains five possible specific answers: A, B, C, D, or U, where:
A = High significance
B = Moderate significance
C = Low significance
D = Insignificant
U = Unknown

Answer A conveys the maximum number of points and the ratio of values for A, B, C, and D is always 3: 2: 1: 0.

When possible, a precise answer (single-letter answer) that best characterizes the species should be selected, even if it does not illustrate it accurately. However, answer ranges (AB, BC, CD, AC

[= A, B, or C], or BD [= B, C, or D]) may be used as provisional answers if assessors can remove at least one of the four choices (A, B, C, or D), but do not have sufficient information to give a more precise answer. 'U' (Unknown) should be selected only if none of the four choices can be eliminated when a reasonable attempt cannot answer the question. The answer should be left blank (i.e., not reviewed) if the question has not been considered substantially. A brief text comment (including examples), with citations for all important information sources used, should be provided to justify and document each answer (including the screening questions).
For each species (or infraspecific taxon) assessed, the Dataform should include a header section recording such information as the scientific and common names of the species, region of interest, assessor's name, and date the current assessment was completed.

3.2.1.4 Calculation of the Subranks

Each answer to each question is assigned a point value, and these points (or point ranges for answer ranges such as AB or BC) are used to calculate subranks for each of the four sections. The various questions in each section are weighted differently to reflect their relative contributions to the topic addressed by that section.

For each section, breakpoints between the subrank intervals are rounded to integers where necessary. The points for each answer in a section are totaled, which determines the corresponding subrank. To accommodate situations in which one or more questions are answered with an answer range (e.g., AB) or with 'Unknown' (effectively the answer range AD), the minimum and maximum possible point totals for each section can then be calculated by separately adding up the lowest and highest possible points for each answer. On the other hand, for questions answered with a single letter (e.g., A), the minimum and maximum point totals are the same.

Table-1: Subranks Calculation

	A	B	C	D	Points		Subranks
I. ECOLOGICAL IMPACTS						**Subrank I Intervals**	
Q1.	33	22	11	0	0-33		
Q2.	18	12	6	0	0-18	78-102	High
Q3.	18	12	6	0	0-18	52-77	Medium
Q4.	9	6	3	0	0-9	27-51	low
Q5.	24	16	8	0	0-24	0-26	Insignificant
II. CURRENT DISTRIBUTION AND ABUNDANCE						**Subrank II Intervals**	
Q6.	15	10	5	0	0-15	28-36	High
Q7.	15	10	5	0	0-15	19-27	Medium
Q8.	3	2	1	0	0-3	10-18	low
Q9.	3	2	1	0	0-3	0-9	Insignificant
III. TREND IN DISTRIBUTION AND ABUNDANCE						**Subrank III Intervals**	
Q10.	18	12	6	0	0-18		
Q11.	3	2	1	0	0-3	55-72	High
Q12.	9	6	3	0	0-9	37-54	Medium
Q13.	18	12	6	0	0-18	19-36	Low
Q14.	6	4	2	0	0-6	0-18	Insignificant
Q15.	9	6	3	0	0-9		
Q16.	9	6	3	0	0-9		
IV. MANAGEMENT DIFFICULTY						**Subrank IV Intervals**	
Q17.	18	12	6	0	0-18	39-51	High
Q18.	15	10	5	0	0-18	27-38	Medium
Q19.	15	10	5	0	0-15	14-26	Low
Q20.	3	2	1	0	0-3	0-13	Insignificant

If the maximum and minimum point total for a subrank both fall in a single subrank interval, the result is a precise subrank *(e.g.,* Medium). However, if they fall into different subrank intervals, the result is a subrank range *(e.g.,* High/Medium). Note that if the maximum and minimum point totals yield a subrank range of High/Insignificant, the subrank should be listed as 'Unknown' since no possibilities have been excluded.

3.2.1.5 Calculation of the I-Rank

The four subranks (either precise subranks or subrank ranges) are in turn used to determine the overall I-Rank by a similar process used to calculate the individual subranks. The subranks for each section are assigned their own relative weights to reflect their relative contributions to the species' overall impact on biodiversity.

Table-2: Invasive Species Impact Rank Calculation

SECTION	SUBRANK VALUES				POINTS	I-RANK INTERVALS	I-RANK
	High	**Medium**	**Low**	**Insignificant**			
	A	**B**	**C**	**D**			
I. Ecological Impact	50	33	17	0	0-50		
II. Current Distribution and Abundance	25	17	8	0	0-25	76-100	High
						51-75	Medium
III. Trend in Distribution and Abundance	15	10	5	0	0-15	26-50	Low
						0-25	Insignificant
IV. Management Difficulty	10	7	3	0	0-10		

If any subrank is not precise, but is instead a range *(e.g.,* High/Medium) or is 'Unknown' (effectively High/Insignificant), the minimum and maximum point totals for the pertinent section are calculated by separately tallying the lowest and highest points. The resulting precise I-Rank or I-Rank range is then determined. A two-step or three-step I-Rank range is acceptable *(e.g.,* Medium/Low or High/Low) since at least one possible rank has been excluded.

However, if the maximum and minimum point totals do not exclude any of the four possible I-Ranks (High/Insignificant), the I-Rank should be listed as 'Unknown'.

3.2.1.6 I-Rank Reasons Summary

Briefly summarize the significant information about the species' four subranks and its I-Rank in a text statement. This text should be written to view only, appropriate for use as a summary section in reports.

3.2.1.7 Information Sources

Finally, citing the various publications, experts, and other information sources mentioned to in the text comments, as well as other important sources checked in finalizing the assessment.

3.3 Identifying the Applicability of the Protocol in Large Scale by Analyzing the Obtained Categories of Invasive Trees

After applying the "Invasive Species Assessment Protocol", we prepared a list of invasive alien tree species into four categories i.e., high, medium, low, or insignificant negative impacts to native biodiversity.

Then by analyzing the categories with information availability, we identified whether the "Invasive Species Assessment Protocol" fits for broad scale applicability i.e., the protocol can be applied to other plants (herbs, shrubs or weeds) to prepare a complete list of invasive alien plants in Bangladesh or no not.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Results

4.1.1 A list of Invasive Tree Species

A total of 23 tree species were listed after reviewing all the available published articles and books related to the invasive species in Bangladesh (Table -3). This 23 species were assessed using "Invasive Species Assessment Protocol".

Table-3: A preliminary list of invasive tree species in Bangladesh

Sl. No.	Local name	Scientific name	Sources
1.	Eucalyptus	*Eucalyptus camaldulensis* Dehnh.	Rahman *et al.* (2010). Rana, M. P., & Akhter, F. (2010). Zabala, N. Q. (1990).
2.	Eucalyptus	*Eucalyptus brassiana* S.T. Blake.	Zabala, N. Q. (1990).
3.	Eucalyptus	*Eucalyptus tereticornis* Sm.	Zabala, N. Q. (1990).
4.	Eucalyptus	*Eucalyptus grandis* W. Hill ex Maiden	Rahman, M. H., & Roy, B. (2014). Khan *et al.* (2011).
5.	Akashmoni	*Acacia auriculiformis* A.Cunn. ex Benth.	Rahman *et al.* (2010). Mukul, *et al.* (2006). Zabala, N. Q. (1990).
6.	Mangium	*Acacia mangium* Willd.	Rahman *et al.* (2010). Mukul, *et al.* (2006). Zabala, N. Q. (1990).
7.	Sissoo	*Dalbergia sissoo* Roxb. ex DC.	Zabala, N. Q. (1990). Rahman, M. H., & Roy, B. (2014). Khan *et al.* (2011).

Sl. No.	Local name	Scientific name	Sources
8.	Malacana koroi	*Paraserianthes (Albizia) falcataria* (L.) Nielsen.	Zabala, N. Q. (1990). Khan *et al.* (2011). Rahman, M. H., & Roy, B. (2014).
9.	Telekadam/ Eplepil	Leucaena leucocephala (Lam.) de Wit.	Zabala, N. Q. (1990). Rana, M. P., & Akhter, F. (2010). Mukul, *et al.* (2006).
10.	Caribaea pine	*Pinus caribaea* Morelet.	Zabala, N. Q. (1990).
11.	Pine	*Pinus oocarpa* Schiede *ex* Schltdl.	Zabala, N. Q. (1990).
12.	Mahogany	*Swietenia macrophylla* G. King.	Rana, M. P., & Akhter, F. (2010). Mukul, *et al.* (2006). Zabala, N. Q. (1990).
13.	True mahogany	*Swietenia mahagoni* (L.) DC.	Rana, M. P., & Akhter, F. (2010). Mukul, *et al.* (2006). Zabala, N. Q. (1990).
14.	Teak	*Tectona grandis* L.f.	Rana, M. P., & Akhter, F. (2010). Mukul, *et al.* (2006). Zabala, N. Q. (1990). Khan *et al.* (2011). Rahman, M. H., & Roy, B. (2014).
15.	Pynkado	*Xylia dolabriformis* Benth.	Zabala, N. Q. (1990).
16.	Ban/Nona Jhau	*Tamarix indica* Willd.	Biswas *et al.* (2007).
17.	Bon-jam/ Kak-jam	*Syzygium fruticosum* (Roxb.) DC.	Biswas *et al.* (2007).
18.	Modhufol	*Salacia prinoides* (Willd.) DC.	Biswas *et al.* (2007).

Sl. No.	Local name	Scientific name	Sources
19.	Karancha	*Pongamia pinnata* (L.) Pierre.	Biswas *et al.* (2007).
20.	Batul, Batley	*Excoecaria indica* (Willd.) Muell.Arg.	Biswas *et al.* (2007).
21.	Jhau	*Pinus elliottii* Engelm.	Rana, M. P., & Akhter, F. (2010). Mukul, *et al.* (2006).
22.	Siris	*Albizia odoratissima* (L. f.) Benth.	Rana, M. P., & Akhter, F. (2010). Mukul, *et al.* (2006).
23.	Oil-palm	*Elaeis guineensis* Jacq.	Rana, M. P., & Akhter, F. (2010). Mukul, *et al.* (2006).

4.1.2 Ranking Invasive Tree Species in Bangladesh

The 23 species were gone through two screening questions at first and then followed twenty assessment questions which are grouped into four sections: Ecological Impact, current distribution and abundance, trend in distribution and abundance, and management difficulty. The answers were used to calculate a subrank for each of the four sections. An overall I-Rank is then calculated from the subranks for the 23 species.

4.1.2.1 Ecological Impact

To answer the questions of this section, we focused on the individual tree's current negative impacts on native plant or animal, ecosystem processes or ecological communities. After assessing, *Dalbergia sissoo*, *Eucalyptus grandis*, and *Leucaena leucocephala* got high rank which is between 78-102. On the other hand, *Acacia auriculiformis* is in medium, and *Elaeis guineensis* is in low rank while twelve species are in high to medium, medium to low or high to low rank of subrank I (Ecological impact) (**Figure 3**). The species in high rank indicate that they have serious adverse impacts on native biodiversity and ecosystem processes. When the range of rank varies

significantly such as *Eucalyptus brassiania* lies in high to low rank, it denotes that the questions under this subrank could not be precisely answered or available information was not enough. It is factual for all the subranks.

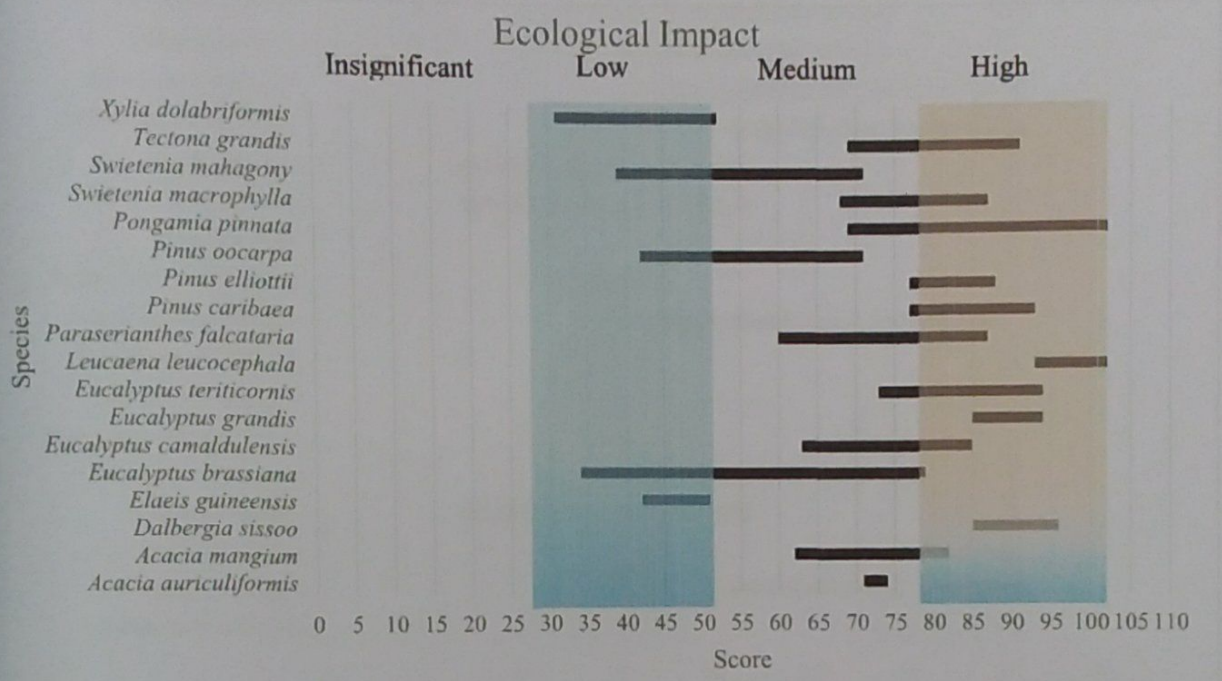

Figure 3: Species with subrank I (Ecological impact) scores.

4.1.2.2 Current distribution and abundance

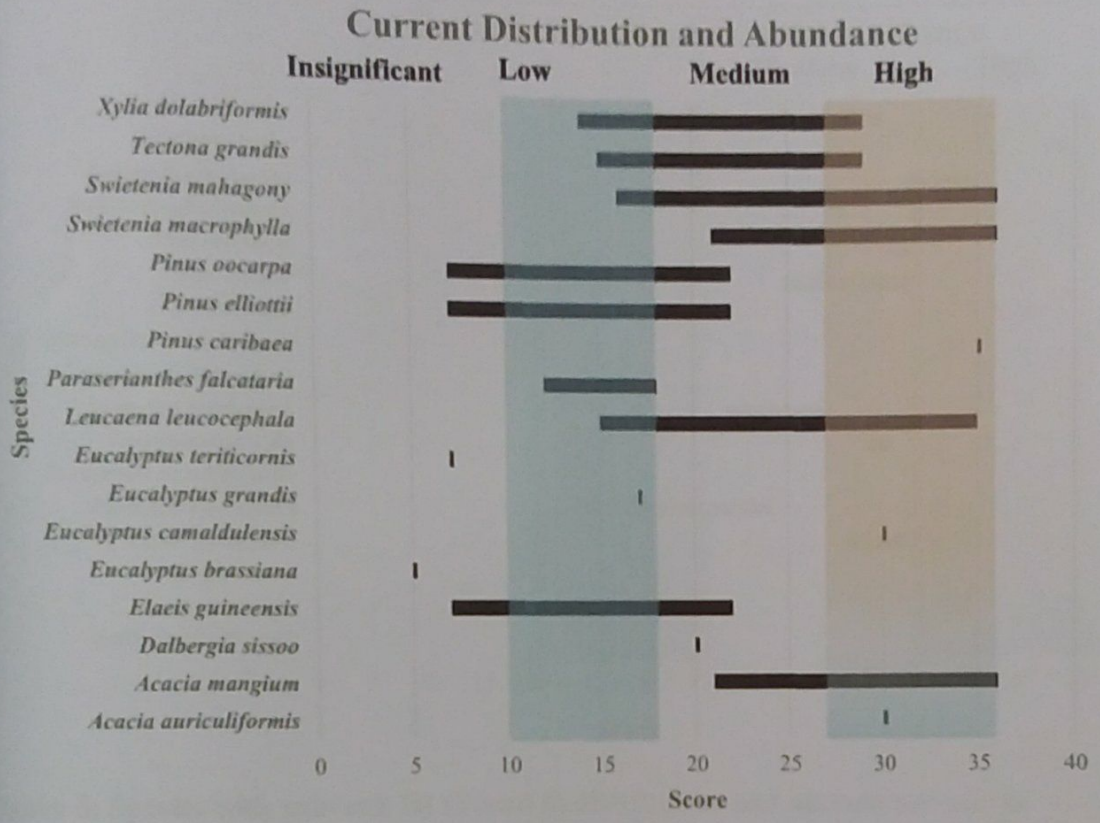

Figure 4: Species with subrank II (Current distribution and abundance) scores.

It is more practical to define the species' generalized range to answer the questions in this section. Three species such as *Acacia auriculiformis*, *Eucalyptus camaldulensis*, *Pinus caribaea* got high rank ranging between 28-36 after the assessment. Contrary, *Dalbergia sissoo* is in medium, *Eucalyptus grandis* is in low and *Eucalyptus teriticornis* and *Eucalyptus brassiana* are in insignificant rank while ten species are in high to medium, high to low, medium to low, medium to insignificant rank of subrank II (Current distribution and abundance) (**Figure 4**). The species with higher current distribution and abundance value represents that the total damage caused by the species will be greater as it covers large areas.

4.1.2.3 Trend in distribution and abundance

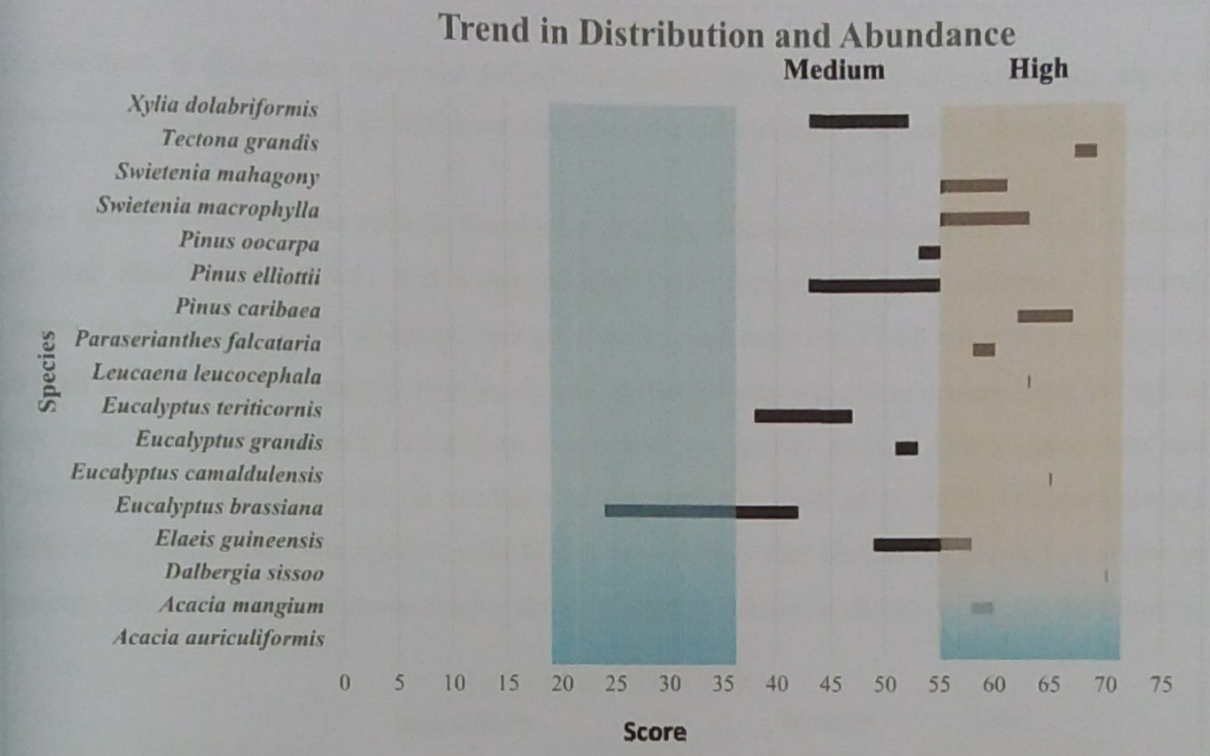

Figure 5: Species with subrank III (Trend in distribution and abundance) scores.

Estimates of the species' current range, its possible potential range in the region, and its current rate of spread help to answer questions in this section. After completing the assessment, ten species get high rank between 55-72 and three species such as *Eucalyptus grandis*, *Eucalyptus teriticornis*, *Xylia dolabriformis* get medium rank between 37-54 while three species such as *Elaeis guineensis*, *Pinus elliottii* and *Pinus oocarpa* are in high to low and *Eucalyptus brassiana* is in medium to low rank of subrank III (Trend in distribution and abundance) (**Figure 5**). The species in high rank indicate that they have a higher potential for further spread to uninfested distant portions of the country and cause a higher damage to biodiversity.

4.1.2.4 Management difficulty

The questions in this section assess the difficulty of control, the accessibility of invaded sites where it threatens natural diversity and the likelihood that known control measures will cause collateral damage to

native species. Three species such as *Eucalyptus grandis*, *Leucaena leucocephala*, *Pinus caribaea* get high rank between 39-51 and 4 species such as *Dalbergia sissoo*, *Eucalyptus brassiana*, *Swietenia mahagony*, *Xylia dolabriformis* get medium rank between 27-38 while five species are in high to medium, two species such as *Acacia auriculiformis* and *Pinus oocarpa* are in high to low rank, *Acacia mangium* is in medium to low and two species such as *Elaeis guineensis* and *Paraserianthes falcataria* are in medium to insignificant rank of subrank IV(Management difficulty) (**Figure 6**). The species with higher rank denote that they are difficult to control or prevent from spreading and have a higher chance of causing substantial damage to nearest biodiversity.

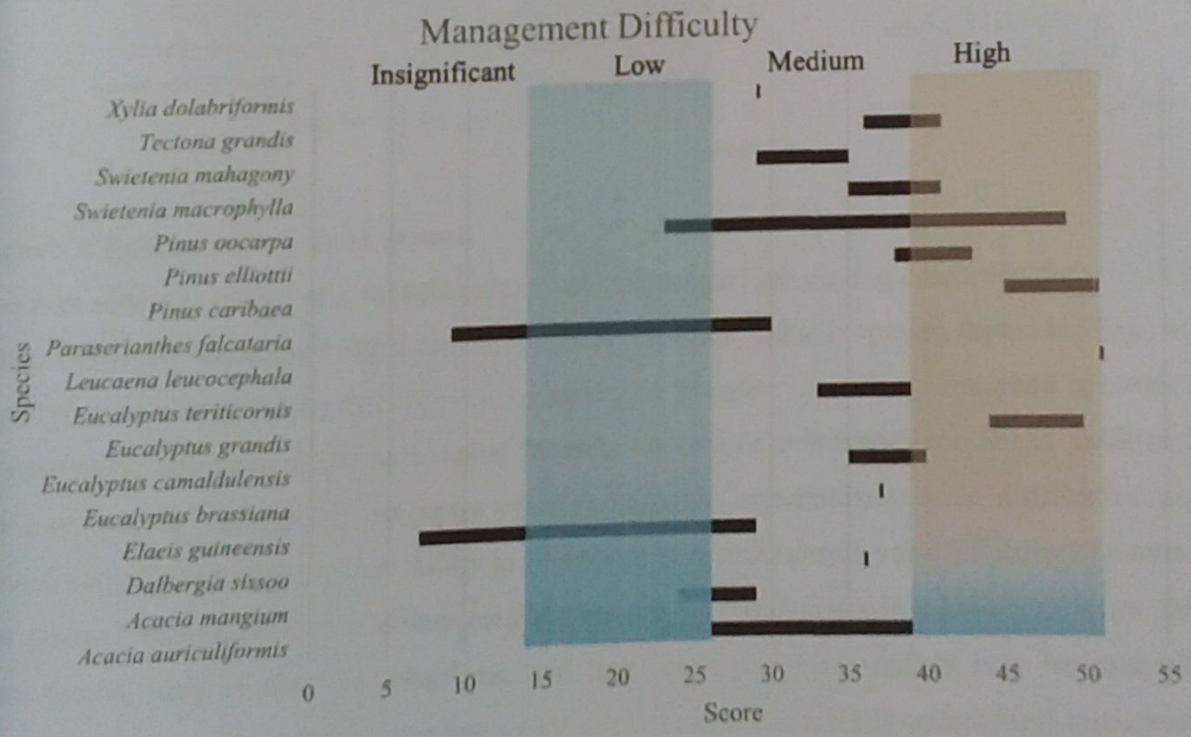

Figure 6: Species with subrank IV (Management difficulty) scores.

4.1.2.5 Invasive Species Rank (I-Rank)

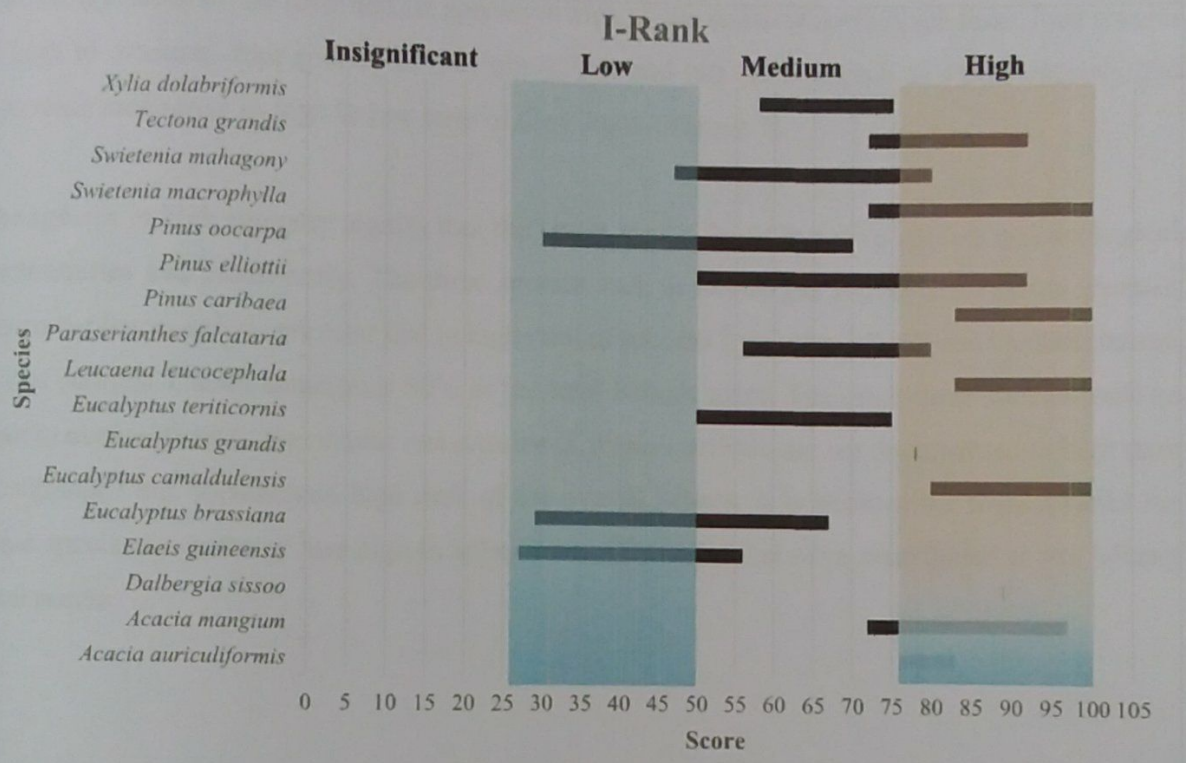

Figure 7: Species with I-Rank scores.

The four subranks (either precise subranks or subrank ranges) are used to determine the overall I-Rank. Generally speaking, factors which can push a species' I-Rank upward (towards High) are the ability to change ecosystem processes; ability to invade relatively undisturbed ecological communities; ability to cause substantial impacts on rare or vulnerable species or ecological communities, or high-quality examples of more common communities; wide distribution and general abundance where present; ability to disperse to new areas readily; and difficulty of control. The protocol recognizes that a species may impact natural biodiversity in a variety of ways, that these factors vary in their contributions, and that some important factors may be mutually exclusive. For example, a species that has a wide current range and already occupies all appropriate habitats within a region of interest (Section II) cannot continue to expand its range in the same region of interest (Section III).

When the scores for the four subranks are totaled, and when compared to the I-Rank intervals, the score total determines the overall invasive species assessment rank (I-Rank) of the individual species. By doing so, we recorded six species in high, *Xylia dolabriformis* in medium, four species in high to medium, four species in medium to low and two species such as *Pinus elliottii*, and *Swietenia mahagony* in high to low rank of the I-Rank (**Figure 7**).

The species in high category signify that they pose severe threat to native species and ecological communities and biodiversity. The three species such as *Dalbergia sissoo*, *Eucalyptus grandis*, *Leucaena leucocephala* are recorded in high rank of subrank I and also I-Rank and its main reason is that subrank I score constitutes 50% of the total I-Rank score. The other three species such as *Acacia auriculiformis, Eucalyptus camaldulensis, Pinus caribaea* are not documented in high rank of subrank I but documented high rank of the overall I-Rank. It is because the impact ranks for these species are more or less high in subranks II, III and IV that have contributed to the I-Rank total scores.

4.1.3 Categories of invasive tree species using the "Invasive Species Assessment Protocol"

Table-4: Categories of invasive tree species in Bangladesh

Category types of invasiveness	Name of the species
High	1. *Acacia auriculiformis* A.Cunn. ex Benth. 2. *Dalbergia sissoo* Roxb. ex DC. 3. *Eucalyptus camaldulensis* Dehnh. 4. *Eucalyptus grandis* W. Hill ex Maiden 5. *Leucaena leucocephala* (Lam.) de Wit. 6. *Pinus caribaea* Morelet.
High/Medium	1. *Acacia mangium* Willd. 2. *Paraserianthes (Albizia) falcataria* (L.) Nielsen. 3. *Swietenia macrophylla* G. King. 4. *Tectona grandis* L.f.
High/Low	1. *Pinus elliottii* Engelm. 2. *Swietenia mahagoni* (L.) DC.
Medium	1. *Xylia dolabriformis* Benth.
Medium/Low	1. *Elaeis guineensis* Jacq. 2. *Eucalyptus brassiana* S.T. Blake. 3. *Eucalyptus tereticornis* Sm. 4. *Pinus oocarpa* Schiede *ex* Schltdl.

4.1.4 List of species which are not fit for applying "Invasive Species Assessment Protocol"

The following listed species cannot be selected for applying "Invasive Species Assessment Protocol" because only non-native species can be categorized by this protocol. *Salacia prinoides* (Willd.) DC. was excluded as no record is available whether it is native or non-native.

Table-5: A list of species which are not fit for applying "Invasive Species Assessment Protocol"

Sl. No.	Name of the species	Termed as invasive	Termed as native
1.	*Albizia odoratissima* (L.f.) Benth.	Rana, M. P., & Akhter, F. (2010). Mukul et al. (2006).	Sana, D.L. (1989). Troup, R.S. (1921). Orwa et al. (2009). Rajeswari, V., & Paliwal, K. (2007).
2.	*Excoecaria indica* (Willd.) Muell. Arg	Bisaws et al. (2007).	Ellison et al. (2010).
3.	*Tamarix indica* Willd.	Bisaws et al. (2007).	Apu et al. (2012). Sarker, M. A. M., & Sarker, M. A. M. (2009).
4.	*Syzygium fruticosum* (Roxb.) DC.	Bisaws et al. (2007).	Dutta et al. (2015).
5.	*Pongamia pinnata* (L.) Pierre.	Bisaws et al. (2007).	Mahmood, H. (2015).
6.	*Salacia prinoides* (Willd.) DC.	Bisaws et al. (2007).	No record found.

4.2 Applicability of the Protocol in Assessing and Categorizing the Invasiveness of all Non-native Plant Species

Applying the "Invasive Species Assessment Protocol", we haven't got any low or insignificant category invasive species, because those tree species assessed have already been reported to have different level of invasiveness in the literature. In some cases, we couldn't give precise answers to few questions in different subranks and we have to make assumptions to answer the questions. For example, in subrank I- impact on individual native plant or animal species, in subrank II-proportion of current range where it negatively impacts biodiversity, in subrank III- inherent ability to invade conservation areas and other native species habitats, in subrank IV- general management difficulty, impacts of management on native species: these are some worth mentioning questions that are difficult to answer precisely from the existing information on particular species.

We have to face several problems while identifying, assessing and categorizing the invasive tree species in Bangladesh. The main the problem is the definition of species invasiveness. Because nationally, we don't have any definition. So, published paper used it haphazardly. Invasive, alien

or exotic terms are used interchangeably or simultaneously by different authors. So when they found the origin of a species from another country, they described it invasive alien despite any knowledge on the invasiveness of the species. Secondly, there is lack of ecological information of specific species because very little species-wise knowledge about their interaction with other species are available. Thirdly, most information of invasiveness comes from laboratory trial without much field trial. Unfortunately, there are very limited numbers of experimental and observational studies of invasive plant species impacts on native species, communities, and ecosystems found in our country.

But still, the protocol has provided significant results in categorizing the listed species despite inadequate information source. The protocol can be applied properly in large scale in assessing and categorizing all the non-native plants including trees, herbs, shrubs, and weeds if we can provide ample information regarding the species exact current distribution and abundance, silviculture, its management and consequent impacts etc. For this, we need more research and survey for those relevant species.

Forest Department or other organizations can utilize this protocol with some modification in preparing a national list of invasive alien plants in Bangladesh.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5. Conclusion and recommendation

5.1 Conclusion

From the listed twenty-three invasive trees, we could able to rank seventeen species. Six species were excluded from the list, of which five species are native and no record is available for *Salacia prinoides* if it is native or not. As invasive species assessment protocol is applicable for non-native species, these species were not assessed. When the overall I-Rank was calculated from the values of the four subranks, we got six species in high rank, one species in medium rank, four species in high to medium rank, four species in medium to low rank and two species in high to low rank. From this ranking, it is easily realized to get idea about the relevant species invasiveness and its negative impact on native biodiversity. In this study, we only assessed the invasive trees, but this freely available and flexible protocol can be applied for assessing and categorizing all the non-native plants in order to prepare a national list with some modification of the protocol if needed.

This study has some limitations which are as follows:

- Time is a major limitation of this study because huge time is deeded in answering the questions of the protocol. That's the reason why have chosen the already reported invasive trees not all the non-natives.
- Knowledge about the species is also a major constraint. The ecological interaction of the species with other species, its silvicultural features, management etc. are not known available as per the requirement of the protocol.

5.2 Recommendation

One of the main threats to the world's biodiversity is the introduction of invasive alien species due to its adverse impact on biodiversity, economy and human health (Biswas et al. 2007, Mooney and Hobbs 2000). Like other countries, we should play our part in fighting against the invasive alien species at the individual, community, national or international level. As there is no national list of invasive plant species, a national protocol should be developed or the "Invasive species assessment protocol" should be utilized with some modification in assessing and categorizing the invasive plants of our country. Research on the ecology of the invasive species (long and short term) should be extended to get precise information regarding the species.

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Appendix 1

Invasive species assessment protocol questions

Section I. Ecological impact (five questions, 50% of I-Rank score)

1. Impact on ecosystem processes and system-wide parameters (33 points maximum)
2. Impact on ecological community structure (18 points maximum)
3. Impact on ecological community composition (18 points maximum)
4. Impact on individual native plant or animal species (9 points maximum)
5. Conservation significance of communities and native species threatened (24 points max)

Section II. Current distribution and abundance (four questions; 25% of I-Rank score)

6. Current range size in region (15 points maximum)
7. Proportion of current range where it negatively impacts biodiversity (15 points max)
8. Proportion of region's biogeographic units invaded (3 points maximum)
9. Diversity of habitats or ecological systems invaded in region (3 points maximum)

Section III. Trends in distribution and abundance (seven questions; 15% of I-Rank score)

10. Current trend in total range within the region (18 points maximum)
11. Proportion of potential range currently occupied (3 points maximum)
12. Long-distance dispersal potential within region (9 points maximum)
13. Local range expansion or change in abundance (18 points maximum)
14. Inherent ability to invade conservation areas and other native spp. habitats (6 points)
15. Similar habitats invaded elsewhere (9 points maximum)

16. Reproductive characteristics (9 points maximum)

Section IV. Management difficulty (four questions 10% of I-Rank score)

17. General management difficulty (18 points maximum)
18. Minimum time commitment (15 points maximum)
19. Impacts of management on native species (15 points maximum)
20. Accessibility of invaded areas (3 points maximum)