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Aquatic Invasive Species and Related Impacts on Native Biota in Indonesia

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Doctoral thesis for state exam

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SUMMARY

SURYA GENTHA AKMAL. Aquatic Invasive Species and Related Impacts on Native Biota in Indonesia. This research is under supervised by JIŘÍ PATOKA

The research on aquatic invasive species and how they are impacting Indonesian native biota has revealed the serious ramifications that the introduction of invasive species has on Indonesian freshwater and marine ecosystems. This study highlighted the escalating problems caused by invasive species, in terms of both biodiversity and the entire ecosystem.

This research has shown the aquatic invasive species introduced into Indonesian waters can successfully compete with indigenous biota for limited resources. They commonly have strong competitive advantages allowing them to spread out rapidly and occupy habitats that were previously inhabited by native species. In some cases, the invasive species can completely replace indigenous species, resulting in a dramatic decrease in biodiversity.

The research also brings to the attention the importance of invasive species control and prevention efforts. With meticulous research and monitoring efforts, it is possible for scientists to identify new invasive species entering Indonesian waters and take necessary actions to prevent their spread. The controlling of existing invasive species is also necessary to reduce their impact on native biota and ecosystems.

Overall, the study on aquatic invasive species and their impacts on Indonesian native biota highlights the significance of raising consciousness and protecting the biodiversity of Indonesian waters. The conservation, surveillance and controlling of invasive species should be improved to protect indigenous species and ensure the ecosystem balance in Indonesian waters.

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1. INTRODUCTION

1.1 Background

The introduction of aquatic invasive species is the starting point for the main cause of biodiversity loss (Williams-Subiza and Epele, 2021). Invasive alien species whose presence and spread are environmentally, economically, and human health damaging (Akmal et al., 2021; Pimentel, 2011; Williams-Subiza and Epele, 2021). Indonesia is rich in biodiversity, Wallace noticed a sharp divide in the distribution of animals in the Indonesian archipelago (Fig. 1) (Brewer, 2022). Based on data from the Ministry of Maritime Affairs and Fisheries, there are at least 4,720 species of both marine and freshwater fish in Indonesia.

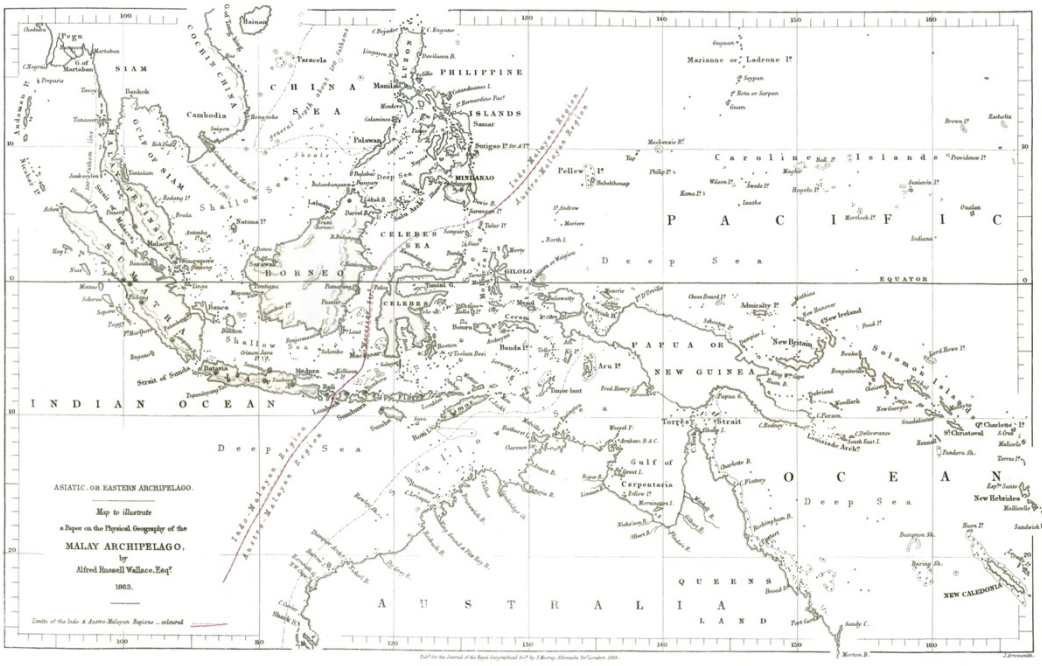

Figure 1 The original drawing of the Wallace Line; the division between Asian and Australasian animals and plants (Brewer, 2022).

Aquatic ecosystems in Indonesia are adaptive for both native and non-native organisms (Patoka et al., 2016). Invasive species are known to have serious impacts on biodiversity (McNeely, 2001). Naturally, the movement of organisms is isolated by nature thus forming a unique diversity. Natural isolation in the form of oceans, rivers, deserts and mountains limits the distribution of organisms in ecosystem areas. International trade and the global movement of livestock, wildlife and animal products are enormous and cross the natural borders (Fèvre et al., 2006). Thus, the

increased risk of biological invasion is a consequence of globalization (Meyerson and Mooney, 2007). Several invasive species are known to pose serious threats to native biota and have profound impacts on entire ecosystem via suppressed growth, pathogen transmission, competition, hybridization, habitat alteration, and prey on native species (Peeler and Taylor, 2011; Strauss et al., 2012; Torchin et al., 2003).

Invasive species cause environmental and socio-economic losses throughout the world (Pimentel, 2011). The spread of invasive species has recently increased in aquatic ecosystems in Indonesia both in vertebrates (Marková et al., 2020; Muchlisin, 2012; Patoka et al., 2020) and invertebrates (Marwoto et al., 2018; Putra et al., 2018). The increase in invasive species can sometimes be economically beneficial, but it is also necessary to consider and predict the impact of the introduction on aquatic ecosystems (Yonvitner et al., 2020). The existence of new species complicate the management of fish stocks and biodiversity conservation in invaded waters also because the current legislative regulations are ineffective in many cases (Patoka et al., 2018).The decline in freshwater biodiversity due to species invasion is one form of ecological losses. Early prevention can be done by monitoring the spread of alien species so that their invasion can be controlled in the environment. Early and accurate detection is an effective strategy to control the ecological impacts of species that enter (Mehta et al., 2007).

1.2 Research objectives and scientific hypotheses

The primary objective of this research was to describe alternatives to management to mitigate the effects of non-native invasive species, including preventive, control, and eradication strategies as well as taking socioeconomic effects into account for each management strategy. Thus, it can provide recommendations for policy development and management actions that are effective and sustainable, including monitoring, research, and public education. To achieve these main objectives, there are several steps of research that need to be carried out and become the specific objectives of this research, i.e.:

a. To determine the invasive species present in Indonesian aquatic environments and evaluate the likelihood of their spread.

b. To assess the impact of invasive species on native biota, including alterations to community structure, ecosystem function, and natural characteristics.
c. To evaluate factors affecting species invasions and their impacts, such as environmental conditions, biological characteristics of invasive species, and interactions with other species.

The hypotheses used in this research are:

H_0 = The number of invasive species in Indonesia is not increasing.

H_1 = The number of invasive species in Indonesia is increasing.

H_2 = Education of general public in case of risks related to release of non-native species is poor.

1.3 Benefit of research

The purpose of this research is to provide the following advantages:

a. To know about the types of invasive species and their impact on native biota in certain waters so that effective and appropriate control efforts can be implemented.
b. To increase the understanding on species invasion process and the factors that contribute to it, so more effective strategies for prevention can be improved.
c. To provide useful information regarding cost-effective and sustainable management approaches to mitigate the consequences of non-native invasive species, which can help to minimize both economical and ecological losses.
d. To increase the community's awareness regarding the importance of protecting biodiversity and healthy aquatic ecosystems.
e. To provide advice and recommendations for policy development and better management actions regarding the mitigation of invasive species and the conservation of indigenous biota.
f. To expand insights and scientific knowledge on species invasions and their impacts on aquatic ecosystems, which can be the basis for further

investigations and developing innovative methods and technologies to manage species invasions.

1.4 Research framework

One of the most important ecosystems for the survival of human beings and other biota is the aquatic ecosystem. However, the waters are frequently targeted by invasive species which can negatively impact on biodiversity and ecosystem health (Alidoost Salimi et al., 2021). Aquatic Invasive Species are introduced species that originate from other ecosystems and then spread to other waters, harming the surrounding environment and affecting the indigenous biota.

The occurrence of Aquatic Invasive Species can affect aquatic ecosystems in multiple ways. They may compete with indigenous biota for resources such as nourishment and habitat, affect nutrient availability, and also introduce new diseases or parasites (Gallardo et al., 2016; Hassan and Nawchoo, 2020a; Havel et al., 2015). Consequently, the spreading of Aquatic Invasive Species may lead to a reduction in populations of native biota, decreasing biodiversity and interfering with the functionality of aquatic ecosystems (Hassan and Nawchoo, 2020a; Thomaz et al., 2015).Therefore, it is important to understand and solve the issues related to the invasion of species and their impacts on native biota in a certain water body. If we understand the varieties of Aquatic Invasive Species present in certain waters and how they might be interacting with native biota, it is possible to implement appropriate and effective management to reduce the negative consequences of Aquatic Invasive Species on aquatic ecosystems and indigenous biota (Vander Zanden and Olden, 2008).

Moreover, the importance of species invasion research is to understand the factors that impact species invasion, such as climate, geography and human activities. Through understanding these factors, it is feasible to develop more effective prevention strategies to discourage the introduction of Aquatic Invasive Species (Heilman, 2014). It will provide recommendations for policy development and effective and sustainable management actions, including monitoring, research, and public education.

2. LITERATURE REVIEW

2.1 Definition and characteristics of Aquatic Invasive Species

Aquatic invasive species is a species that introduces into a new aquatic or aquatic environment and has the possibility to spread and have negative impacts on the environment (Havel et al., 2015; Kovalenko et al., 2021a), including on the indigenous biota inhabiting it, these species can originate from different regions or countries and then spread to a new area, either by human activities or naturally occurring pathways (Baker et al., 2022; Lodge et al., 2006; Mooney and Cleland, 2001; Wilson, 2010).

The general characteristics of aquatic invasive species are quick and highly adaptable reproduction, and the possibility of altering the environment in which they occur through physically or biochemically modifying it, thereby inhibiting the establishment of native species and damaging ecosystems (Thomaz et al., 2015). Some characteristics which make them potentially a significant threat to the viability of aquatic ecosystems include (Rafferty, 2023):

a. Rapidly growing and reproducing species that are highly adaptable to new environments.
b. The species capable of competing with indigenous species in the same waters can replace the indigenous species and reduce biodiversity.
c. The species is capable of efficiently exploiting the resources of the water body, thus causing resource competition between the alien species and the native species in the same water body.
d. Easily dispersed species that occupy a large range of aquatic habitats, both the deepest and the shallowest, as well as exploiting a variety of substrate types throughout the waters they inhabit.

2.2 Habitat and environment of Aquatic Invasive Species

The increasing intensity of global trade and transportation systems has led to an increase in the introduction of non-native species in Indonesia (Nijman et al., 2022, 2021). The introduction of non-native aquatic species is one of the activities that originated from human activities and has impacts that are not predictable (Ju et al., 2020; Tarkan et al., 2021). The development of recreational fisheries and

aquaculture activities has a significant effect on the spread of alien fish (Cambray, 2003; Davis and Darling, 2017; Haubrock et al., 2022; Lauber et al., 2020; Smith et al., 2020).

Non-native species can potentially become invasive and cause ecological disasters such as extinction of native species and ecosystem imbalance (Manchester and Bullock, 2000). One of the impacts that can occur is the disruption of fish community structure and changes in ecosystem food webs (Durante et al., 2022; He et al., 2021). Biomass changes of the community structure will show the impact of alien species on the ecosystem balance (Hedianto & Purnamaningtyas 2011). The study of non-native species is part of the management of alien species. This is important because the sooner management occurs, the more easily it can be anticipated the impacts of alien species in an ecosystem (Wittenberg & Cock 2001; Koehn & MacKenzie 2004).

The impacts of invasive aquatic species can also be felt economically (Akmal et al., 2021; Cuthbert et al., 2021). They can be devastating to fishing and aquaculture industries, impair water quality, damage infrastructure such as irrigation canals or hydropower installations, and disrupt the tourism and recreation sectors associated with waterways (Lin et al., 2022). The control of invasive aquatic species is a challenging endeavor. Several methods of control include monitoring and early detection, removal of invasive species from infested habitats, use of natural predators, trapping, and selective use of chemicals (Rafferty, 2023).

Prevention is also an important aspect of invasive aquatic species control. Through strict regulations on the trade and transportation of invasive species, as well as public awareness and education campaigns, it is possible to reduce the risk of invasive species introducing into aquatic habitats (Heilman, 2014; Sulpizio, 2020). Ongoing studies and research on aquatic invasive species are important to fully comprehending their impacts, enhancing control methods, and developing effective protection strategies for aquatic ecosystems.

Cooperation between the government, research institutes, universities, businesses and communities is crucial in dealing with the problem of invasive aquatic species. It is only through concerted efforts, strict supervision, and appropriate control measures that we can protect aquatic habitats and environments

from invasive species invasion and maintain the biodiversity that is essential to ecosystems and the balance of nature.

2.3 Impact of Aquatic Invasive Species in the ecosystem

As the trade of living aquatic products, both animals and plants, is increasingly dynamic between countries and between areas within the country, the introduction of various types of aquatic species in the destination area has proven to pose a significant threat to the sustainability of the local ecosystem (García-Berthou et al., 2005). The introduction of exotic aquatic species is generally dominated by the trade of aquatic products, ornamental fish trade, fish restocking, including the introduction and rearing of new aquatic animal species at fishing sites, which has become a worldwide trend and Indonesia is no exception (Muchlisin, 2012; Yanuarita et al., 2020). Various fishing locations that offered the sensation of hunting monster/predator fish became a new business field and stimulated people to develop the same thing in various places.

Some invasive species can be effective predators of indigenous species (Doherty et al., 2016; Rafferty, 2023). They may lack natural predators in their new environments, so they can prey on indigenous species with high success and reduced abundances and diversity of native species (Hejda et al., 2009; Mooney and Cleland, 2001). Aquatic ecosystems' habitat structure and species composition may be impacted by invasive aquatic species. As an example, they could modify the structure of aquatic plants or their density on the water's substrate (Gallardo et al., 2016; Mayfield et al., 2021). Such alterations may have an impact on both organisms that rely on specific habitat structures and biodiversity (Astegiano et al., 2015; Decena et al., 2020; Dennis, 2018; Jackson and Fahrig, 2013; Pinho et al., 2020). The movement of energy and nutrients in the ecosystem can be hampered by the introduction of invasive aquatic species into the food chain. They have the power to alter the food cycle and the structure of interdependence among organisms in the food chain (Gallardo et al., 2016; Hassan and Nawchoo, 2020b; Havel et al., 2015).

Aquatic invasive species can have a variety of negative effects on native species' the ability to reproduce and chances of surviving (Havel et al., 2015). They might

feed on eggs, larvae, or juveniles, which could decrease the likelihood of the following generation surviving (Mayfield et al., 2021). Some aquatic invasive species have the potential to spread pathogens or parasites that can harm native species (Foster et al., 2021). The spread of these diseases may have a detrimental effect on the numbers of indigenous species and the stability of the ecosystem. Although invasive aquatic species are frequently seen as threats, they can fill deficiencies or add new advantages to ecosystems (Havel et al., 2015; Katsanevakis et al., 2014; Kovalenko et al., 2021b). For example, they can act as predators that help control populations of other potentially harmful organisms. Invasive aquatic species can also affect nutrient cycling in aquatic ecosystems (Vanni, 2021). They can alter the composition of nutrients in the water or change the process of decomposing organic matter (Capps and Flecker, 2013; Jo et al., 2017). This can affect water quality and affect other organisms in the ecosystem that depend on a balanced nutrient cycle.

On the other hand, aquatic invasive species can also provide a new food resource for other organisms in the ecosystem (Havel et al., 2015). Some invasive species may become abundant prey for indigenous predators or become an alternative food supply when native species are declining in population. Although rare, there is also the possibility of invasive species forming symbiotic relationships with native organisms in the ecosystem (Linders et al., 2019). This can involve a relationship of mutualism, where both species mutually benefit each other (Prior et al., 2015), or a relationship of parasitism (Yuan and Li, 2022), where the invasive species benefits and the native organisms are harmed (Drew et al., 2021). It is important to note that although aquatic invasive species can have complex roles in ecosystems, the negative impacts they have on native species and ecosystems as a whole often outweigh the benefits they provide (Havel et al., 2015; Thomaz et al., 2015). Therefore, efforts to control and prevent the invasion of invasive species are essential to protect the biodiversity and balance of aquatic ecosystems.

2.4 Distribution and dispersal of aquatic invasive species

Aquatic invasive species spread and dispersal refers to the way an invasive species spreads from its native habitat to a new aquatic environment (Jones et al.,

2021; Sulpizio, 2020). The spread of invasive species can occur through various mechanisms and factors. One of the main factors in the spread of aquatic invasive species is human transportation (Ascensão and Capinha, 2017; Hulme, 2009; Yuliana et al., 2021). Invasive species can spread through ships, boats, or other means of transportation used to transport goods or people between waters (Hulme, 2009; Rothlisberger et al., 2010). Eggs, larvae or adults of invasive species may attach to the exterior of the vessel or transportation device and then be released into a new environment when the vessel or device is used in other waters (Rothlisberger et al., 2010). This is especially true when rivers or waterways connect different ecosystems or when floods carry invasive species from one region to another.

Environmental changes such as climate change, changes in water temperature, deterioration in water quality or changes in habitat can also affect the distribution and spread of aquatic invasive species (Sulpizio, 2020). Environmental changes can create more favorable conditions for invasive species to survive and reproduce in new environments (Hanley and Roberts, 2019; Havel et al., 2015). For example, increased water temperatures caused by climate change can allow invasive species from warmer regions to invade waters that were previously too cold for them (IUCN, 2021; NISAW, 2021).

Human activities such as the introduction of invasive species for fishing, aquarium or aquaculture purposes can also lead to the dispersal of aquatic invasive species (Giovos et al., 2019). When invasive species are introduced to new environments by humans, they can quickly spread and settle in waters that were previously inaccessible to them. The high adaptability and reproductive ability of invasive species also affect their spread. Invasive species often have the ability to adapt to a wide range of environmental conditions and have high reproductive rates (Cleeland et al., 2020; Deacon et al., 2011; Tiebre et al., 2007; Whitney and Gabler, 2008). This allows them to quickly populate and dominate the environment.

Biological control is the intentional manipulation of natural enemies by humans for the purpose of controlling pests and reducing the population of the prey. This method targets the invasive species and can involve different organisms, such as insects, mites, nematodes, and pathogens (USDA, n.d.). Introduction of biological control agents, which are usually nonindigenous themselves, is a common

management response to disease or pest outbreaks. Breadth of impact of biological control agents is one of the primary criteria used to evaluate and rank the risks that control agents pose to nontarget organisms (Ewel et al., 1999).

Beginning in the mid-1980s, Indonesia introduced integrated pest management (IPM) as a new crop management approach (Thorburn, 2015; Wiyono, 2020). The Indonesian IPM program is an example of a large-scale participatory approach to the management of complex pest problems. The program is best known for introducing the innovative farmer field school model of agroecosystem-based experiential learning. IPM can be a sustainable approach to pest management, but it requires careful consideration of the ecological and economic factors involved (FAO, 2019).

It is important to note that while pest control can introduce pests, it can also be used to prevent their introduction. IPM, for example, can be used to manage pests in a sustainable way and prevent the introduction of exotic pests (Wiyono, 2020).

2.5 Management efforts for aquatic invasive species

In an effort to manage aquatic invasive species, prevention and control measures are essential. Prevention efforts involve strict oversight of human transportation, such as vessel inspections and effective water ballast management (Ascensão and Capinha, 2017; Giovos et al., 2019; Rothlisberger et al., 2010). Public awareness campaigns can also help prevent the spread of invasive species by increasing understanding of their negative impacts (Tricarico, 2022).

Aquatic invasive species control can involve actions such as population monitoring, culling and removal of invasive species (Giovos et al., 2019). The control methods used may vary depending on the species involved and the environment affected. A few control methods include the use of naturally occurring predators, application of insecticides and herbicides, commercial fishing, and using mechanical methods such as trimming or trapping (Kovalenko et al., 2021a; Thomaz et al., 2015).

It is important that effective management of aquatic invasive species requires cooperation between authorities, scientists, stakeholders, and the general public. Attempts made to reduce the distribution of invasive species and recover

ecosystems affected by these invasions are imperative to preserve the ecological balance and sustainability of water resources.

2.6 Regulations and policies in Indonesia

The concern of the government in preventing the spread of invasive and harmful aquatic species has started since the 80s with the enactment of the Decree of the Minister of Agriculture No. 179/Kpts/Um/3/1982 on the Prohibition of the Import of Several Dangerous Fish Species from Abroad. In the following decade, the participation of Indonesia in the international level in terms of environmental sustainability was proven by its involvement in the ratification of the United Nations Convention on Biological Diversity in 1992 and the ratification of the convention in Law No. 5 of 1994 concerning the Ratification of the United Nation Convention of Biological Diversity.

The convention recognizes that human activities in utilizing biological resources have disrupted the balance of ecosystems in various parts of the world. Therefore, all countries are required to participate in maintaining the sustainability and preservation of global biodiversity because the conservation and sustainable use of diverse biological resources is a collective interest shared by all countries to meet the needs of food, health and other needs for the world's growing population, where access and utilization must be carried out fairly both in managing these biological genetic resources and in terms of developing technology for their utilization.

To anticipate the increasingly dynamic distribution of invasive and dangerous aquatic species, the government then issued several regulations to replace the Decree of the Minister of Agriculture No. 179/Kpts/Um/3/1982, including the Regulation of the Minister of Marine Affairs and Fisheries No. 17 of 2009 concerning the prohibition of the entry of several dangerous fish species into the territory of Indonesia. In this ministerial regulation, there are 30 species of fish both fresh and marine that are prohibited from entering the territory of the Republic of Indonesia where if these types of fish are found at the place of entry, namely seaports, river ports, airport crossing ports, post offices, border posts with other countries determined by the Minister, then destruction by fish quarantine officers is

mandatory. If the dangerous aquatic species are found outside the place of entry, it is mandatory to carry out the orderly implementation of laws and regulations in the field of fisheries by fisheries inspectors.

During the implementation of Ministerial Regulation No. 17 of 2009, it was found that there were more types of aquatic animals that could potentially threaten the preservation of environmental resources so that in 2014 a revision of Ministerial Regulation No. 17 of 2009 was issued through Ministerial Regulation No. 41 of 2014 which contained a ban on the entry of 152 types of aquatic animals into the territory of Indonesia. Unfortunately, the ministerial regulation does not regulate the prohibition, procedures and rules for the traffic of dangerous fish species between areas within the territory of Indonesia so the Head of the Fish Quarantine and Inspection Agency in 2016 issued a notification letter no 1140/BKIP.2/K.140/X/2016 that in regulating the traffic of dangerous fish species to be rejected in accordance with Ministerial Regulation No. 41 of 2014 except for export activities are still allowed if they have met the requirements of the destination country.

Furthermore, in 2016, the Ministry of Environment and Forestry issued Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number P.94/MENLHK/SETJEN/KUM.1/12/2016 concerning Invasive Species. Considering the massive trade of invasive and dangerous fish species, especially between areas within the territory of Indonesia that are not through the entry and exit gates and the high economic value of trading these fish species so that some people are still not moved to have awareness to prevent the distribution of prohibited aquatic animals, it is necessary to remember that Law Number: 45 of 2009 concerning Amendments to Law Number: 31 of 2004 concerning Fisheries strictly regulates the prohibition of stocking aquatic species that can pose a threat to local fish resources, fish source environments, and human health.

Realizing the high threat of the spread of invasive and dangerous aquatic species through various activities of trade in live fish products and activities of utilizing exotic aquatic species for various other purposes, public participation and awareness need to be increased, one of which is through dissemination and empowerment of all stakeholders who utilize aquatic resources so that the

implementation of KP Ministerial Regulation No. 41 of 2014 and Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number P.94 / MENLHK / SETJEN / KUM.1 / 12/2016 concerning Invasive Species can run optimally.

3. MATERIAL AND METHODS

Various methods were developed through conventional approaches (direct observation) and molecular approaches. The conventional approach has several weaknesses, including that it is difficult to collect, takes a long time to process, costs a lot of money, and tends to destroy the habitat (Minamoto et al., 2012; Santas et al., 2013). Therefore, other methods that are more effective and efficient are needed to validate the existence of target species, one of which is the molecular approach.

3.1 Study area

Indonesia, the largest archipelago in the world with no less than 13,466 named islands and about 11,000 of them inhabited, is known as one of the Mega-Biodiversity countries with a high level of endemicity (Maskun et al., 2021; Sanka et al., 2023). Due to the history of geological activity that led to the formation and dispersal of large and small islands, there was a long-standing isolation of plant and animal species (Boedhihartono, 2017; Handayani et al., 2021). The location between two continents, Asia and Australia, and between two oceans, the Pacific and the Indian, also has a significant role in the rich biodiversity of Indonesia. The western region is strongly linked to Peninsular Malaysia and Asia, known as the Sunda Shelf, while the eastern region is strongly linked to Papua and Australia, known as the Sahul Shelf. But in between is an area that is not linked to either Asia or Australia, namely Sulawesi and its surrounding islands, which have a unique and complex geological history, resulting in a very high level of endemicity in Indonesia.

As one of the ten countries with high biodiversity, Indonesia occupies an important position in the world biodiversity map. This biodiversity has a very important role for human life and the environment, including as a source of food and medicine, reservoirs, maintaining the carbon cycle and so on. In terms of endemicity, Indonesia has 20% of the 1,605 bird species (323 species) and 53% of the 720 mammal species (382 species) in the world that are found to live naturally in Indonesian territory. As an archipelago, Indonesia has no less than 95,181 km^2 of coastline surrounded by tropical oceans, which adds to its high level of

biodiversity. Conservation International (CI) has designated Indonesia as one of the 17 "Megadiversity Countries" that has 2 of the 25 "Biodiversity Hotspots" in the world. In addition, Indonesia also has 18 of WWF's (World Wide Fund for Nature) "200 Global Eco-regions", 24 of Birdlife International's 218 "Endemic Bird Areas", and has 10% of the world's flowering plant species and is a center of biodiversity and animal husbandry, as well as a center of coral reef diversity, both plant and animal.

The alarming decline in biodiversity richness needs to be addressed immediately because without a comprehensive response, this decline is expected to continue until it reaches a point of no return. In addition, the spread of invasive species, both from within the country (inter-island and local/foreign) and from abroad, has caused increasing pressure on native species and ecosystems. These natural changes can be caused by climate change that affects the growth rate of a species both locally and on a wider scale and reduced competition with other species.

A full range of all relevant habitats for Indonesia will be covered, including large rivers and small streams, a thermal streams, natural lakes and man-made reservoirs, flooded quarries, small islands, marine, and fishponds. We also personally visited exporters/wholesalers in Indonesia, as well as government agencies related to the research. freshwater invasive species will be actively searched for at most sampling locations by manual examination of suitable shelters to confirm their in-situ presence. More activities will be added according to obtained data. An inventory of ornamental fish in Indonesia was conducted by contacting ornamental fish hobbyists, fish sellers, the Regional Fisheries Agency and the Fish Quarantine Agency in Indonesia via telephone and WhatsApp. Findings indicating the species' presence were confirmed by data, photographs, and personal interviews with residents and fishers. All activities were carried out in compliance with Indonesian laws and ethical rules and warranted by Indonesian academic staff from the IPB University. Data on domestic production and trade, export and import were obtained from the Fish Quarantine and Inspection Agency and the Ministry of Marine Affairs & Fisheries of the Republic of Indonesia.

3.2 Data analysis

The data collecting and analysis will be processed in cooperation with the Charles University, the University of South Bohemia, the IPB University, and the Indonesia Open University.

3.2.1 Climate matching analysis

Contemporary climate data were downloaded at a 10 arcminutes spatial resolution from the WorldClim dataset (Fick and Hijmans, 2017) and environmental layers of future climate data (CSIRO A1B) were obtained from the CliMond database (v.1.2, https://www.climond.org/; Kriticos et al. 2012) at a 10 arc-minutes spatial resolution. We calculated 19 bioclimatic variables (Table 1); these represent the average, extreme and variation of temperature and precipitation and are widely used in ecological niche modelling. Both datasets were assembled in QGIS 3.22.2 'Białowieża' and were released on 17.12.2021 (https://qgis.org/en/site/) to ASCII format for use with the MaxEnt algorithm (Phillips, 2005). MaxEnt was chosen because it is one of the best performing algorithms with presence-only data (Elith et al., 2010). The model describes an area of the continued likelihood of habitat relevance in the target area. Bioclimatic variables provide a statistical summary of the climate within a set of static spatial variables that are appropriate for bioclimatic modelling. Climatic similarity based on temperature characteristics was modelled from a dataset of environmental layers and the native range of species using the MaxEnt program (v.3.4.1; https://biodiversityinformatics.amnh.org /open_source/maxent) to test its environmental suitability. As a cumulative result, a continuous map was created and visualized in QGIS 3.22.2 'Białowieża'. If the climate suitability value reaches or exceeds a certain threshold value, this is interpreted as no evidence of a climate constraint on the survival of the species and is indicated by a red area on the map within the expected native range of the species. MaxEnt was trained using all 19 bioclimatic variables with default features and regularization multipliers (Default model), which are based on empirical tuning studies (Phillips and Dudík, 2008).

Additionally, the conservation status, trends and threats of each listed species by the IUCN Red List of Threatened Species (https://www.iucnredlist.org/) were

included if known. Following categories are included in the IUCN Red List: Extinct (there is no reasonable doubt that the species is no longer extant); Extinct in the wild (survives only in captivity); Critically endangered (facing an extremely high risk of extinction in the wild); Endangered (facing a very high risk of extinction in the wild); Vulnerable (facing a high risk of extinction in the wild); Near threatened (close to being at high risk of extinction); Least concern (unlikely to become extinct in the near future); and Data deficient (more information is required for a proper assessment of conservation status).

Table 1. Bioclimatic variables are used in the variable selection strategy to build a climate similarity model in Indonesia.

Bioclimatic variables	
BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3	Isothermality (BIO2/BIO7) (×100)
BIO4	Temperature Seasonality (standard deviation ×100)
BIO5	Max Temperature of Warmest Month
BIO6	Min Temperature of Coldest Month
BIO7	Temperature Annual Range (BIO5-BIO6)
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter

3.2.2 Morphological analysis

The morphological parameter measurements were species-specific, for example, in crayfish, thes measurements included: ocular carapace length, chela length, propodal membrane length, dactyl length, chela width, cephalon width, thorax width, carapace depth, total carapace length, abdominal length, telson length, telson width, abdominal width, uropod length, cheliped (1st pereiopod) length, 2nd-5th pereiopod lengths, weight, and rostral spine count. Morphological parameter measurements were used for strain comparison. All linear measurements were made with vernier calipers (accuracy 0.1 mm) to nearest mm. Weight was measured on an Adam CB-1001 1,000 g/0.01 g digital electronic weight scale to nearest gram. Abnormal deformations such as bifid or curved rostrum (Yuliana et al., 2019) and regenerated claws were excluded from the morphological analysis.

3.2.3 Statistical analysis

Statistical analysis is the process of collecting and analyzing data to discern patterns and trends. In the papers part of this dissertation, we use descriptive statistics which involves collecting, interpreting, analyzing, and summarizing data to present it in the form of charts, graphs, and tables. For exaple, in crayfish, the Kruskal Wallis method was used to determine significant morphometric differences between the crayfish groups at their source regions. Discriminant analysis was used to determine population groupings based on different locations. The software used for discriminant analysis was the IBM SPSS Statistics for Windows, Version 23.0. Armonk.

4. THE PLANNED OUTPUTS

The collected data will be continuously published in impacted scientific journals such as Scientific Reports, Knowledge and Management of Aquatic Ecosystems, Coastal Management, Management of Biological Invasions, Aquatic Living Resources, Aquaculture Environment Interactions, Biologia, etc. The results are presented in the form of scientific publications in the aforementioned dissertation. Some of our research results are in preparation and under review. The manuscripts are expected to be published as soon as possible, some of them are:

a. Akmal SG, Yonvitner, Yulianda F, Adrianto L, Patoka J. Potential spread of invasive crayfish used as life bait by Indonesian anglers. **Under review** in Human Dimensions of Wildlife.
b. Akmal SG, Yonvitner, Yulianda F, Jerikho R, Slavík O, Bláha M, Kouba A, Patoka J. The farmer's enemy: The hazards of freshwater crab *Parathelphusa convexa* de Man, 1879 spreading to paddy fields in West Sumatra, Indonesia. **In preparation** and will be submitted to journals with impact factors indexed by WoS or Scopus.
c. Patoka J, Akmal SG, Bláha, M, Kouba A. *Cherax woworae*, a new crayfish (Decapoda: Parastacidae) from West Papua Province, Indonesia. **Under review** in Zootaxa.
d. eDNA of aquatic invasive species in Indonesi. **In preparation** and will be submitted to journals with impact factors indexed by WoS or Scopus.

5. LIST OF REFERENCED LEGISLATION

The list of legislation referenced in this study are:

a. Decree of the Minister of Agriculture No. 179/Kpts/Um/3/1982 on the Prohibition of the Import of Several Dangerous Fish Species from Abroad.
b. Law No. 5 of 1994 concerning the Ratification of the United Nation Convention of Biological Diversity.
c. Regulation of the Minister of Marine Affairs And Fisheries of the Republic of Indonesia No. 17 of 2009 concerning the prohibition of the entry of several dangerous fish species into the territory of Indonesia.
d. Regulation of the Minister of Marine Affairs And Fisheries of the Republic of Indonesia No. 41/Permen-Kp/2014 concerning the prohibition of the entry of several dangerous fish species into the territory of Indonesia.
e. A notification letter no 1140/BKIP.2/K.140/X/2016 that in regulating the traffic of dangerous fish species.
f. Minister of Environment and Forestry of the Republic of Indonesia Number P.94/MENLHK/SETJEN/KUM.1/12/2016 concerning Invasive Species.
g. Law Number: 45 of 2009 concerning Amendments to Law Number: 31 of 2004 concerning Fisheries.

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