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IMPACT OF ALIEN FISHES ON NATIVE FRESHWATER FISH DIVERSITY, ENVIRONMENT AND SOCIOECONOMY IN THE KLANG VALLEY, MALAYSIA

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By

SABA ABDULWAKIL OLAWALE

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Alien species are species that are found outside their native ranges and natural distributions. In Malaysia, information on the ecological and socioeconomic dimensions of these fishes are lacking. Therefore, in general, this study aimed to assess the potential and existing impacts of alien fishes on freshwater biodiversity, environment, and socioeconomy in Klang Valley, Malaysia.

In the first objective of this study, the species composition and invasion risks of alien fish species from pet stores in Klang Valley were measured. A checklist of taxa belonging to 18 orders, 53 families, and 251 species of alien fishes was documented from 60 pet stores. Out of the total of the 53 families, Cichlidae (n = 71) occupied 100% of all Cichliformes recorded, followed by family Cyprinidae (n = 25) which occupied about 67.6% of all Cypriniformes. A total of 91% (n = 228) of the recorded fish species belong to the tropical climatic zone, while 8% (n = 21) and 1% (n = 2) belong to the subtropical and temperate regions, respectively. Based on the IUCN Red List of Threatened Species status, 3% (n = 7) each of the recorded species had been categorized as endangered (EN) and near threatened (NT), while 4% (n = 11) and 1% (n = 4) had been categorized as vulnerable (VU) and critically endangered (CR), respectively. Alien fish species were significantly (U = 159.0, $p < 0.001$) higher in number (Mdn = 25) compared to the native fish species (Mdn = 6). Besides, Spearman rank correlation indicated a significant positive association between the number of alien fish and the total number of fish species ($r = 0.969$, $p < 0.001$) recorded. Fish Invasiveness Screening Test (FIST) showed that seven (30.43%), eight (34.78%), and eight (34.78%) species were considered to be high, medium, and low invasion risks, respectively. As a result, nine species (39.13%) were of high invasion risk.

In the second objective, the alien fish composition and possible impacts on native fishes in selected rivers within Klang Valley were assessed based on a cross-sectional sampling.

A total of 20 fish species consisting of six alien fish species were recorded from six rivers located within Klang Valley. Semenyih River recorded the highest richness (*Dmn* = 1.32), diversity ($H^{'}$ = 1.80), and evenness (J = 0.87) indices, and the lowest dominance index (C = 0.20). Pusu River recorded the lowest diversity ($H^{'}$ = 0.94) and the highest dominance (C = 0.55) indices. Except for depth, significant differences ($p < 0.05$) existed in the water physicochemical parameters across the sites. Canonical Correspondence Analysis (CCA) revealed six variables with strong loadings from Principal Components Analysis (PCA). Most of the alien species such as Nile tilapia (*Oreochromis niloticus*), Amazon sailfin catfish (*P. pardalis*), and vermiculated sailfin catfish (*P. disjunctivus*) correlated positively with rivers that recorded high ammonia-nitrogen and nitrite, and negatively with those that recorded high phosphate and dissolved oxygen. Moreover, the length-weight relationships (LWR) showed no clear pattern to distinguish between native and alien fishes, while the condition factors (CFs) for alien fishes were significantly ($p < 0.05$) higher than those of their native counterparts.

In the third objective, stomach contents and stable isotope signatures of fish species from three out of the six rivers sampled in the second objective were assessed. Nile tilapia (*Oreochromis niloticus*) recorded the highest percentage of full stomachs and significantly higher stomach fullness indices throughout the sampling sites. Besides, there were similarities in the food categories preferred by both alien and native fishes with Morisita-Horn's diet overlap index (CH) ranging from 0.57 (*Rasbora vulgaris versus O. niloticus*) to 0.88 (*Mystacoleucus singaringan versus O. niloticus*). Apart from *R. vulgaris* with the highest TROPH value (2.60), both alien and native species fall within the same trophic level. Except in a few cases, Kruskal-Wallis and Mann-Whitney's tests revealed mainly no significant differences ($p > 0.05$) between the stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotopes of alien *versus* native fishes from all rivers. Furthermore, the bi plot of $\delta^{15}N$ and $\delta^{13}C$ values showed a similar pattern of trophic similarity between alien and native species from the Gombak River. Generally, the results of stable isotope analysis confirmed the outcome of stomach content analysis. This indicates possible negative impacts on the native fish species through competition for the same trophic resources.

In the fourth objective, the public knowledge and perceptions of the impacts and importance of alien fishes in Malaysia were investigated. Using online and hardcopy questionnaires, a total of 304 responses were analyzed from respondents that included members of the Malaysian Fisheries Society and the Malaysian Freshwater Fish Facebook page with more than 25,000 members, as well as aquarium store owners and hobbyists within Klang Valley. Chi-square (χ^2) test showed that education, followed by ethnicity, gender, and age was the most important factor influencing respondents' knowledge and perceptions. Mostly weak, but significant relationships ($p < 0.05$) were found between different items measuring respondent knowledge *versus* perceptions regarding alien fishes, and between items measuring knowledge and perception *versus* practices regarding alien fishes. A total of 76% of the respondents considered alien fish species as economically valuable, while 57% knew their ecological impacts. Generally, there were significant relationships ($\alpha = 0.05$) between the knowledge of respondents regarding ecological impacts, awareness of alien fish species, perceptions of economic importance, and practices regarding alien fishes.

For the fifth objective, the contribution of alien freshwater fishes to the income of ornamental fish store owners and their attitude towards alien freshwater fishes within Klang Valley was explored. Using face-to-face questionnaires, 70 pet stores were surveyed. Most of the pet store owners were males (72%), Chinese (83%), educated at the secondary level (79%), get a monthly income of RM 2000 to RM 5000 (78%), are married (73%) and had spent between 10 - 20 years in the ornamental fish business (37%). Significant positive correlations were observed between the monthly income level and origin (native or alien) of the most purchased fish ($r = 0.441$; $p = 0.002$), and the number of years in business *versus* percentage income from ornamental fish sales ($r = 0.289$; $p = 0.034$). The contribution of alien freshwater fishes to the income from ornamental fish sale correlated weakly and moderately, but significantly with the general contribution of fish sale to income level ($r = 0.287$; $p = 0.036$), and store owners' attitude ($r = 0.463$; $p = 0.000$) to allowing alien fishes in Malaysia. Chi-square (χ^2) test revealed significant relationships ($p < 0.05$) between the attitude of store owners towards alien ornamental fish species *versus* educational level ($\chi^2 = 16.424$, $p = 0.007$) and contribution of alien ornamental fishes to the pet store owners' income ($\chi^2 = 27.266$, $p = 0.003$), respectively. Fish sales as the main income source also related significantly with the impact of fish selling business on income level ($\chi^2 = 10.448$, $p = 0.007$). Except for the educational level where most of those in the secondary (79%) category agreed and strongly agreed as opposed to 55% of those in the bachelor's category that agreed, with a statistically significant difference ($\chi^2 = 16.424$, $p = 0.007$), most of the respondents agreed that alien freshwater ornamental fish species should be allowed and there was no significant difference between their attitudes ($p > 0.05$).

In conclusion, this study revealed the number of high-risk alien ornamental fish species that gives an awareness of possible future invasion in Klang Valley, Malaysia. Besides, six alien fish species were recorded from selected rivers in Klang Valley. Rivers with higher alien species occurrences were characterized by lower fish diversity, higher ammonia and nitrite concentrations, and greater exposure to anthropogenic activities. Besides, alien fishes were generally more robust, indicating their potential or existing impacts. Generally, Malaysians have good knowledge of the negative impacts of alien fishes with a perception that these fishes are economically important. Finally, the alien ornamental fish sale is important to the businesses of store owners, and the educational level influences their attitude to alien ornamental fish culture and sale in Malaysia.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

IMPAK IKAN ASING KE ATAS DIVERSITI IKAN AIR TAWAR TEMPATAN, PERSEKITARAN DAN SOSIOEKONOMI DI LEMBAH KLANG, MALAYSIA

Oleh

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Spesies asing adalah spesies yang terdapat di luar kawasan semulajadi dan taburan asal mereka. Di Malaysia, maklumat mengenai aspek ekologi dan sosioekonomi ikan asing sangatlah kurang. Oleh itu, secara keseluruhannya, kajian ini adalah bertujuan untuk menilai potensi dan kesan yang ada pada ikan asing terhadap diversiti air tawar tempatan, persekitaran, dan sosioekonomi di Lembah Klang, Malaysia.

Untuk objektif pertama kajian ini, komposisi spesies dan risiko pencerobohan ikan asing dari beberapa kedai haiwan peliharaan sekitar Lembah Klang telah diukur. Senarai semak taksa yang terdiri daripada 18 order, 53 keluarga, dan 251 spesies ikan asing telah didokumentasikan dari 60 kedai haiwan peliharaan. Dari jumlah 53 keluarga, Cichlidae (n = 71) menduduki 100% dari semua Cichliformes yang dicatatkan, di ikuti oleh keluarga Cyprinidae (n = 25) yang menduduki sekitar 67.6% dari semua Cypriniformes. Sebanyak 91% (n = 228) spesies ikan yang direkodkan berasal daripada zon beriklim tropika, sementara 8% (n = 21) dan 1% (n = 2) masing-masing tergolong daripada wilayah subtropika dan beriklim sederhana. Berdasarkan status IUCN Senarai Merah Spesies Terancam, 3% (n = 7) dari setiap spesies yang direkodkan adalah dikategorikan sebagai terancam (EN) dan hampir terancam (NT), sementara 4% (n =11) dan 1% (n = 4) dikategorikan sebagai rentan (VU) dan sangat terancam (CR). Spesies ikan asing adalah signifikan (U = 159.0, $p < 0.001$) lebih tinggi jumlahnya (*Mdn* = 25) berbanding spesies ikan asli (*Mdn* = 6). Selain itu, korelasi Spearman menunjukkan hubungan positif yang signifikan antara jumlah ikan asing dengan jumlah spesies ikan ($r = 0.969$, $p < 0.001$). Ujian Pemeriksaan Pencerobohan Ikan (FIST) menunjukkan bahawa masing-masing tujuh (30.43%), lapan (34.78%), dan lapan (34.78%) spesies dianggap mempunyai risiko pencerobohan yang tinggi, sederhana, dan rendah. Hasilnya, sembilan (39.13%) spesies mempunyai risiko tinggi dalam pencerobohan.

Untuk objektif kedua, komposisi ikan asing dan kesan terhadap ikan asli di beberapa sungai terpilih sekitar Lembah Klang telah dinilai berdasarkan persampelan secara keratan-rentas. Sejumlah 20 spesies ikan yang mempunyai enam spesies ikan asing telah direkodkan daripada enam sungai di sekitar Lembah Klang. Sungai Semenyih mencatatkan kekayaan tertinggi (*Dmn* = 1.32), kepelbagaian (*H'* = 1.80), dan indeks kesamarataan (*J* = 0.87), dan indeks dominasi terendah (C = 0.20). Sungai Pusu mencatat kepelbagaian terendah (*H'* = 0.94) dan indeks dominasi tertinggi (C = 0.55). Selain kedalaman, terdapat perbezaan yang signifikan ($p < 0.05$) antara parameter fizikokimia air di semua lokasi. Analisis Koresponden Kanonikal (CCA) mendedahkan enam pemboleh ubah yang kuat daripada Analisis Komponen Utama (PCA). Sebilangan besar spesies asing seperti ikan tilapia (*Oreochromis niloticus*), ikan bandaraya (*P. pardalis* dan *P. disjunctivus*) berkorelasi positif dengan sungai-sungai yang mempunyai kandungan ammonia-nitrogen dan nitrit yang tinggi, dan negatif dengan sungai yang mempunyai fosfat dan oksigen terlarut. Tambahan pula, hubungan panjang-berat (LWR) tidak menunjukkan corak yang jelas untuk membezakan antara ikan asli dan asing, sedangkan faktor kondisi (CF) untuk ikan asing jauh lebih tinggi ($p < 0.05$) berbanding dengan ikan asli.

Untuk objektif ketiga, kandungan perut dan analisis isotop stabil spesis ikan dari tiga daripada enam sungai berdasarkan persampelan objektif kedua telah dinilai. Ikan tilapia (*Oreochromis niloticus*) mencatatkan peratusan perut penuh tertinggi dan indeks kepenuhan perut yang signifikan tinggi dari keseluruhan lokasi persampelan. Selain itu, terdapat persamaan dalam kategori makanan yang disukai oleh ikan asing dan ikan asli dengan indeks tumpang tindih diet Morisita-Horn (C_H) antara 0.57 (*Rasbora vulgaris* melawan *O. niloticus*) hingga 0.88 (*Mystus singaringan* melawan *O. niloticus*). Selain *R. vulgaris* dengan nilai TROPH tertinggi (2.60), kedua-dua spesies asing dan asli berada dalam tahap trofik yang sama. Kecuali dalam beberapa kes, ujian Kruskal-Wallis dan Mann-Whitney menunjukkan bahawa tidak terdapat perbezaan yang signifikan ($p > 0.05$) antara isotop karbon ($\delta^{13}C$) dan nitrogen ($\delta^{15}N$) stabil dari ikan asing berbanding ikan asli dari semua sungai. Selanjutnya, dwi-plot nilai $\delta^{15}N$ dan $\delta^{13}C$ menunjukkan pola persamaan trofik yang serupa antara spesies asing dan asli dari Sungai Gombak. Secara amnya, keputusan analisis isotop stabil mengesahkan keputusan analisis kandungan perut. Ini antara bukti yang menunjukkan kesan negatif ikan asing terhadap spesies ikan asli melalui persaingan bagi mendapatkan sumber trofik yang sama.

Untuk objektif keempat, pengetahuan am dan persepsi masyarakat mengenai kesan dan kepentingan ikan asing di Malaysia telah disiasat. Dengan menggunakan borang soal selidik secara atas talian dan secara salinan keras, sejumlah 304 respon telah dianalisis dari responden yang terdiri daripada ahli Persatuan Perikanan Malaysia dan dari laman Facebook Ikan Air Tawar Malaysia yang mempunyai lebih 25,000 ahli, serta pemilik kedai akuarium dan peminat ikan hiasan di sekitar Lembah Klang. Ujian Chi-square (χ^2) menunjukkan bahawa pendidikan, diikuti oleh etnik, jantina dan umur merupakan faktor terpenting yang mempengaruhi pengetahuan dan persepsi responden. Hubungan yang lemah, tetapi signifikan ($p < 0.05$) telah ditemui antara item berbeza yang digunakan untuk mengukur pengetahuan responden berbanding persepsi mengenai ikan asing, dan antara item yang mengukur pengetahuan dan persepsi berbanding amalan mengenai ikan asing. Sebanyak 76% responden menganggap spesies ikan asing sebagai salah satu kepentingan ekonomi, sementara 57% mengetahui kesan ekologi mereka. Secara amnya,

terdapat hubungan yang signifikan ($\alpha = 0.05$) antara pengetahuan responden mengenai kesan ekologi, kesedaran tentang spesies ikan asing, persepsi kepentingan ekonomi, dan amalan mengenai ikan asing.

Untuk objektif kelima, sumbangan ikan air tawar asing terhadap pendapatan pemilik kedai ikan hiasan dan sikap mereka terhadap ikan air tawar asing di Lembah Klang telah dikaji. Dengan menggunakan soal selidik secara bermuka, 70 kedai haiwan peliharaan telah diselidik. Sebilangan besar pemilik kedai haiwan peliharaan adalah lelaki (72%), berbangsa Cina (83%), berpendidikan di peringkat menengah (79%), memperolehi pendapatan bulanan dari RM 2000 hingga RM 5000 (78%), sudah berkahwin (73%) dan telah menghabiskan masa antara 10 - 20 tahun dalam perniagaan ikan hiasan (37%). Hubungan positif yang signifikan diperhatikan antara tahap pendapatan bulanan dengan asal (ikan asli atau asing) yang paling banyak dibeli ($r = 0.441$; $p = 0.002$), dan jumlah tahun dalam perniagaan berbanding peratusan pendapatan daripada penjualan ikan hiasan ($r = 0.289$; $p = 0.034$). Sumbangan ikan air tawar asing terhadap pendapatan dan penjualan ikan hiasan berkorelasi secara lemah dan sederhana, tetapi signifikan dengan sumbangan umum penjualan ikan kepada tahap pendapatan ($r = 0.287$; $p = 0.036$), dan sikap pemilik kedai ($r = 0.463$; $p = 0.000$) terhadap membenarkan ikan asing di Malaysia. Ujian Chi-square (χ^2) menunjukkan hubungan yang signifikan ($p < 0.05$) antara sikap pemilik kedai terhadap spesies ikan hiasan asing berbanding tahap pendidikan ($\chi^2 = 16.424$, $p = 0.007$) dan sumbangan ikan hiasan asing kepada pendapatan pemilik kedai haiwan peliharaan ($\chi^2 = 27.266$, $p = 0.003$). Penjualan ikan sebagai sumber pendapatan utama juga berkait secara signifikan dengan kesan perniagaan penjualan ikan kepada tahap pendapatan ($\chi^2 = 10.448$, $p = 0.007$). Kecuali untuk tahap pendidikan di mana kebanyakan mereka yang berada di kategori menengah (79%) setuju dan sangat setuju berbanding 55% dari mereka yang berada dalam kategori sarjana yang setuju, dengan perbezaan yang signifikan secara statistik ($\chi^2 = 16.424$, $p = 0.007$), sebahagian besar responden bersetuju bahawa spesies ikan asing air tawar hiasan harus dibenarkan dan tidak ada perbezaan yang signifikan di antara sikap mereka ($p > 0.05$).

Sebagai kesimpulan, kajian ini telah mendedahkan jumlah spesies ikan hiasan asing berisiko tinggi yang memberi kesedaran tentang kemungkinan pencerobohan ikan asing pada masa hadapan di sekitar Lembah Klang, Malaysia. Selain itu, enam spesies ikan asing telah dicatatkan daripada sungai terpilih di sekitar Lembah Klang. Sungai yang mempunyai jumlah spesies asing yang lebih tinggi dicirikan dengan kepelbagaian ikan yang lebih rendah, kandungan amonia dan nitrit yang tinggi, serta pendedahan yang tinggi terhadap aktiviti antropogenik. Selain itu, ikan asing pada umumnya lebih rintang, menunjukkan potensi atau impak mereka yang ada. Secara amnya, rakyat Malaysia mempunyai pengetahuan yang baik mengenai kesan negatif ikan asing dengan persepsi bahawa ikan ini amat penting secara ekonomi. Akhir sekali, penjualan ikan hiasan asing adalah amat penting bagi perniagaan pemilik kedai haiwan peliharaan, dan pendidikan mempengaruhi sikap mereka terhadap budaya dan penjualan ikan hiasan asing di Malaysia.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

AS-ISK	Aquatic Species Invasiveness Screening Kit
AUC	Area Under the Curve
CABI	Centre for Agriculture and Bioscience International
CCSA	Committee for the Coordination of Statistical Activities
CF	Certainty Factor
COVID-19	Corona Virus Disease 2019
DIAS	Database of Introduced Aquatic Species
DNA	Deoxy Ribonucleic Acid
DOF	Department of Fisheries
eDNA	Environmental DNA
FD	Frequency Distribution
FISK	Fish Invasiveness Screening Kit
FIST	Fish Invasiveness Screening Test
GISD	Global Invasive Species Database
IAF	Invasive Alien Fish
ISSG	Invasive Species Specialist Group Database
IUCN	International Union for The Conservation of Nature
LWR	Length-Weight Relationship
MNRE	Ministry of Natural Resources and Environment
MT	Metric Tones
NCIAS	National Committee on Invasive Alien Species
NWGIAS	National Working Group on Invasive Alien Species
ORA	Object Recognition Algorithm
ROC	Receiver Operating Characteristics
SDGs	Sustainable Development Goals
TDS	Total Dissolved Solids

CHAPTER 1

INTRODUCTION

1.1 General introduction

A shadow of doubt has been cast on the possibility of achieving item number two of the United Nation's Sustainable Development Goals (SDGs) of 2012, which seeks to end hunger by the year 2030 (Leal Filho et al., 2020). Aside from many other existing challenges, the current COVID-19 pandemic will likely worsen the situation (CCSA, 2020; Leal Filho et al., 2020). In a bid to achieving food and nutrition security which is also accompanied by some social and economic benefits, many countries had engaged in the importation and culture of certain alien fish species due to their desirable characteristics (Diana, 2009; Ellender and Weyl, 2014; Bartley and FungeSmith, 2018). Malaysia is one of the countries that is benefitting economically from these alien fishes (DOF, 2007; Ng, 2016).

Unfortunately, these alien fishes may get introduced into the local waters either intentionally or inadvertently (Kiruba-Sankar et al., 2018). More so, some of the introduced species may impact negatively on native biodiversity and ecosystem functioning (Cucherousset and Olden, 2011; Khairul-Adha et al., 2013), and these impacts are more significant in freshwater bodies (Taybi et al., 2020).

The diverse array of plant and animal communities in Malaysia which includes about 470 species of freshwater fishes is threatened by several factors among which are the impacts of introduced fish species (Khairul-Adha et al. 2013; MNRE, 2014). Disruption of the receiving environment, overcrowding, and stunting, predation, interspecific competition, the introduction of parasites and diseases, genetic degradation, and extinction of many native fish species are some of the impacts that may arise from the introduction of these alien species (Piria et al., 2018; Miró and Ventura, 2020).

Several pathways of release and dispersal of alien fishes in rivers, lakes, and wetlands have been identified and these include escape or release from fish farms, use as fish bait, and disposal of unwanted aquarium pet (Abdul Salam and Gopinath, 2006; Chong et al., 2010). Besides, some of these fishes were intentionally imported for aquaculture, increased fish stock, aquarium trade, sport fishing, and biological control (DOF, 2004; Chong et al., 2010; Khairul Adha et al., 2013).

In Malaysia, over a period of 11 years (2007-2018), freshwater alien fishes occupied about 93% and 86% of Malaysia's freshwater aquaculture production by weight (1.3 million MT) and wholesale value (RM 7.4 billion), respectively and about 79% of the aquarium fish species by number (DOF, 2018). Also, about 42 freshwater alien fish

species are very popular based on the report of Khairul-Adha et al. (2013).

1.2 Problem statements

An essential first step in evaluating the hazard of alien species to the native ecosystem and species biodiversity which involves the management of invasive alien fishes (Piria et al., 2016), is the analysis of species invasion risks (Lawson et al., 2015; Mendoza et al., 2015; Piria et al., 2016). However, no study had assessed the invasion risks of the alien freshwater fishes in Malaysia where numerous alien fish species have been recorded.

As a guide towards the management of alien fish species, it is important to understand the diversity as well as ecological dynamics that exist between the alien fish species, their native counterparts, and the immediate environment in which they are resident (Weber and Brown, 2011; Zeng et al., 2017). However, no study had investigated the relationship between freshwater quality parameters and fish occurrence for native fishes and their alien counterparts in Malaysia including their state of wellbeing in their resident waterbodies.

Despite the presence and establishment of certain alien fish species in the local water bodies, there remains a dearth of information on the food, feeding habits, and trophic niches of native and alien fish species including the feeding interactions which help to measure possible impacts arising from trophic competition between the native and alien fishes (Khairul-Adha et al., 2013).

Besides that, humans are important components in facilitating and at the same time, managing species invasion (Nanayakkara et al., 2018). The awareness and engagement of the public with issues bordering around inland fish and fisheries would facilitate stronger actions in the conservation of aquatic systems (Cooke et al., 2013). In Malaysia, studies relating to public knowledge, perceptions, attitudes, and practices regarding alien fishes appear to be scarce, and a lack of understanding will hinder management strategies.

Finally, the collection, breeding, and marketing of ornamental fishes is a sizable industry that generates foreign exchange and creates jobs for the locals. Also, there are shreds of evidence that the ornamental fish trade is an important route for alien fish introduction and translocation (Gertzen et al., 2008; Chang et al., 2009; Chan et al., 2019). However, there appears to be a general lack of information on the contribution of the alien ornamental fish industry to livelihoods in Malaysia and the attitudes of freshwater ornamental fish pet store owners towards alien fishes in Malaysia.

1.3 Objectives

The objectives of the study are:

1. To determine the composition and invasion-risks of alien freshwater fishes that are available in pet stores around Klang Valley, Malaysia.

2. To identify the relationship between the occurrence and wellbeing of alien and native fishes and their association with environmental characteristics in selected rivers within Klang Valley, Malaysia.

3. To compare the food preferences and trophic states of native and alien fishes that co-exist in selected rivers in Klang Valley, Malaysia.

4. To determine the influence of socio-demographic factors on the general public's knowledge, perceptions, and practices regarding alien fishes in Malaysia.

5. To determine the economic contribution of alien fishes and pet store owners' attitudes towards the alien fishes in Malaysia.

The objectives in this thesis are described below:

1. Objective 1: The fish aquarium business is one of the important routes of fish introduction into local waters. Therefore, this objective assessed the species composition and invasion risks of fish species from 60 freshwater fish pet stores in Klang Valley, Malaysia in 2019. The alien freshwater fish composition and checklist were prepared, while the Fish Invasiveness Screening Test (FIST) and the Fish Invasiveness Screening Kit (FISK) were used to assess the risks of invasion of these fish species in Malaysian waters.

2. Objective 2: Alien fishes get introduced into local waters through aquarium releases and other sources. This objective, therefore, assessed the native and alien fish species occurrence, diversity, evenness, richness, and dominance of six rivers within Klang Valley (Pusu River, Gombak River, Klang River, Tekala River, Semenyih River, and Langat River), Malaysia and related the fish occurrence with water quality parameters and anthropogenic factors. The condition and general wellbeing of native and alien fishes were employed as a measure of the potential impacts of alien freshwater fishes on their native counterparts by evaluating the length-weight relationships (LWRs) and condition factors (CFs) of the collected fishes.

3. Objective 3: To further ascertain the impacts of alien fishes on their native counterparts, this objective assessed the food composition, trophic level, and trophic overlap between native and alien fishes through the analysis of stomach contents. To complement stomach contents analysis, stable nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) isotope signatures of alien and native fish samples from three selected rivers out of the six rivers sampled in Objective 2 were also measured and compared.

4. Objective 4: A good understanding of the public's knowledge and perception of alien species can guide policymakers to gain support for conservation and management programs. Thus, this objective determined the knowledge, perceptions, and attitudes of the general public judging from socio-demographic characteristics of the Malaysian public using online and hardcopy questionnaires (n = 304). It correlates items measuring respondents' knowledge, perception, and practices regarding alien fishes in Malaysia, and associates these items with the socio-demographic variables.

5. Objective 5: The socioeconomic benefits of these alien fishes contribute to their acceptance and trade. This objective explored the economic contribution and attitude towards alien freshwater ornamental fishes of pet store owners in Klang Valley, Malaysia using hardcopy questionnaires. Aspects of socioeconomic characteristics of ornamental pet store owners and their businesses were correlated and compared. Their attitude towards alien freshwater ornamental fishes in Malaysia was also associated with socio-demographic variables.

1.4 Hypotheses

1. Hypothesis 1:

   H0: Alien freshwater ornamental fishes do not pose a high risk of invasion to the freshwater bodies of Malaysia.

   Hα: Alien freshwater ornamental fishes pose a high risk of invasion to the freshwater bodies of Malaysia.

2. Hypothesis 2:

   H0: There is no relationship between the occurrence and wellbeing of alien and native fishes in selected rivers in Klang Valley, Malaysia, and no association with environmental characteristics.

Hα: There is a relationship between the occurrence and wellbeing of alien and native fishes in selected rivers of Klang Valley, Malaysia, and an association with environmental characteristics.

3. Hypothesis 3:

   H0: There are no differences between the food preferences and trophic states of native and alien fishes that co-exist in selected rivers of Klang Valley, Malaysia.

   Hα: Differences exist between the food preferences and trophic states of native and alien fishes that co-exist in selected rivers of Klang Valley, Malaysia.

4. Hypothesis 4:

   H0: Socio-demographic factors do not influence the general public's knowledge, perceptions, and practices regarding alien fishes in Malaysia.

   Hα: Socio-demographic factors influence the general public's knowledge, perceptions, and practices regarding alien fishes in Malaysia.

5. Hypothesis 5:

   H0: Economic benefit and socio-demographics do not influence pet store owners' attitudes towards the alien fishes in Malaysia.

   Hα: Economic benefit and socio-demographics influence pet store owners' attitudes towards the alien fishes in Malaysia.

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BIODATA OF STUDENT

The student was born on 3rd September 1986 in Lagos, Nigeria. He received his primary education at Satellite Town Primary School, Amuwo-Odofin, Lagos. Afterwards, he continued his secondary education at Satellite Secondary School and Universal Muslim Comprehensive High School both in Amuwo-Odofin Lagos, Nigeria.

His higher education began at the Department of Fisheries, Lagos State University, Nigeria where he obtained a Bachelor's Degree (BSc. Fisheries) with a first-class grade. Thereafter, he proceeded to the University of Lagos for his Master's Degree (MSc. Fisheries Biology and Management) at the Department of Marine Science, where he graduated with distinction. His career as an academic started in 2016 when he joined the School of Agriculture, Lagos State University as a Graduate Assistant.

During his PhD journey, the student had published in reputable peer-reviewed journals, and participated in international conferences under the guidance of his supervisors. The student has a strong research interest in the biodiversity, conservation, and management of fisheries resources and the corresponding human dimensions.

LIST OF PUBLICATIONS

Published Manuscripts

Saba, A. O., Ahmad, I., Syaizwan, Z. Z, Shohaimi, S., Jamil, N. R., Mohd Nawi, N., Abd Ghani, I. F., Abdullah Halim, M. R. and Amal, M. N. A. (2020). Checklists, production trends, and potential ecological and socioeconomic impacts of non-native freshwater fishes in Malaysia: a review. *Aquatic Invasions*, 15(4): 646-670.

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Manuscripts Under Review

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