Borneo Journal of Resource Science and Technology (2022), 12(1): 32-51
DOI: https:doi.org/10.33736/bjrst.4651.2022

Diversity of Fisheries in Sarawak, Northwest Borneo: Present Status and Conservation Issues

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Received: 7 April 2022 Accepted: 10 June 2022 Published: 30 June 2022

ABSTRACT

Information on fisheries resources in East Malaysia is scarce and poorly known. The current review aims to compile a checklist of fisheries resources in the Northwest Borneo (Sarawak, Malaysia) from available published literature, address the resources' present status, and suggest future monitoring needs for selected critical species. The study also aims to determine several Sarawak land-use issues that are in flux and responsible for habitat degradation. Five hundred sixty-four species belonging to 123 families and 32 orders were recorded from Sarawak waters. Freshwater fish species comprised 48.0% of the total, followed by a marine (36.6%), marine-euryhaline (12.9%), and brackish water (2.5%) species. Of this, Cyprinidae was the most dominant group accounting for the greatest number of species (82 species), followed by Balitoridae (34 species), Bagridae (21 species) and Penaeidae (21 species). Therefore, available fisheries resources should be managed carefully as 48 species (9.0%) are currently vulnerable to extinction. Furthermore, the presence of 20 alien species in Sarawak water bodies also requires attention from the authorities due to the potential disruption of aquatic ecological balance. Changing land use issues in Sarawak such as forest degradation, agricultural expansion, peatland deforestation and conversion, logging, destruction of mangrove forests, and construction of hydroelectric power dams and flood mitigation channels pose significant challenges to fishery management in Sarawak. Our study documents the priority of fishery monitoring and conservation in Sarawak water bodies to ensure sustainable management of fisheries resources.

Keywords: checklist, critical species, East Malaysia, fisheries diversity, Sarawak

INTRODUCTION

Fishery resources provide an essential source of protein to humans. The Food and Agriculture Organisation (FAO) reported that humans receive between 15% and 20% of their total animal protein from fish (FAO, 2014). The fisheries sector plays a significant role in economics; it increases the revenue of a country, provides employment opportunities, and reduces poverty among those living in rural areas. Fishery-derived products account for about 10% of agricultural exports globally, and apart from economic returns, the industry is critical in improving food and nutrition security in many developing countries (Chan *et al.*, 2017).

Fish, or aquatic products, has always been a substantial component of the Malaysian diet. On average, each Malaysian consumes more than 50 kg of fish per annum, about 25% of the nation's per capita production. In 2014, the fishery sector in Malaysia produced about 1.98 million tons of fish valued at RM 12.76 billion, which contributed to 1.3% of the country's GDP (DoFM, 2014). Globally, Malaysia is ranked 16th in fishery production, accounting for about 1.1% of world output. However, fisheries production is predicted to increase globally with the increasing human population, where capture fisheries have been the historically dominant source of fish supply (Chan *et al.*, 2017).

Fishery resources are currently subjected to overexploitation, habitat loss and degradation, pollution, by-catch, and human disturbance to meet global demand (Vié *et al.*, 2009; Chong *et al.*, 2010). This pattern is anticipated to lead to local, regional, and eventual global extinction (Arthington *et al.*, 2016). A total of 1951 species of fish have been documented in Malaysian waters. Nearly half are presently threatened to some degree, with two locally extinct species (Chong *et al.*, 2010). Therefore, a holistic approach to fishery management is crucial in ensuring the sustainable exploitation of fishery resources. However, insufficiently updated data on fishery resources form one of the major challenges toward achieving this goal (DoFM, 2015).

Sarawak is a state in Malaysia in the northwestern part of the Island of Borneo (Figure 1), which is extremely rich in biodiversity. However, despite their importance, knowledge and documentation of fisheries in Sarawak are still lacking (Chong *et al.*, 2010). Hence, this study aims to compile a checklist of Sarawak fishery resources, discuss their present status, and suggest future monitoring needs for several critical species. Currently, shifting land use issues in Sarawak could lead to habitat degradation and pose great challenges to fishery management.

MATERIALS AND METHODS

Data on fisheries diversity in the Sarawak area (Figure 1), Malaysia, were extracted from published literatures (Regan, 1906; Watson, 1981; Mohsin & Ambak, 1996; Blaber *et al.*, 1998; Doi *et al.*, 2001; Rajali & Arshad, 2001; Motomura *et al.*, 2002; Parenti & Lim, 2005; Yano *et al.*, 2005; Atack, 2006; Rahim *et al.*, 2009; Ambak, 2010; Chong *et al.*, 2010; Hassan *et al.*, 2010; White *et al.*, 2010; Giam *et al.*, 2012; Nyanti *et al.*, 2012a; Nyanti *et al.*, 2012b; Tan & Lim, 2013; Nyanti *et al.*, 2014; Randall & Page, 2014; Froese & Pauly, 2017). In addition, the name of the species and location of detection was recorded and supplemented with other information extracted from Fishbase (Froese & Pauly, 2017) and Sealifebase (Palomares & Pauly, 2017). Additional data included common name, order, family, habitat, distribution pattern, the occurrence of species in Malaysia, intrinsic extinction vulnerability index (V_i), and economic importance of the species. In contrast, the International Union for Conservation of Nature (IUCN) Red List of each species was taken from the IUCN Red List of Threatened Species database.

The existence of species in Malaysian water bodies, as documented by Fishbase and Sealifebase, was used to gauge the occurrence of species in Sarawak waters (endemic, native, or introduced and alien). However, if a species was not reported, species occurrence was either checked on the IUCN website or declared dependent upon the distribution pattern of the species. Alien species in our paper were marked as "introduced" or "alien". "Introduced" species are those that have been introduced deliberately into the country for aquaculture, aquarium trade, recreational, or biological control purposes, as documented by DoFM (2007); Chong *et al.* (2010) and Rahim *et al.* (2013). Species that showed no historical record of introduction into Malaysia and yet did not fall within the distribution range of a local species, were categorised as "alien".

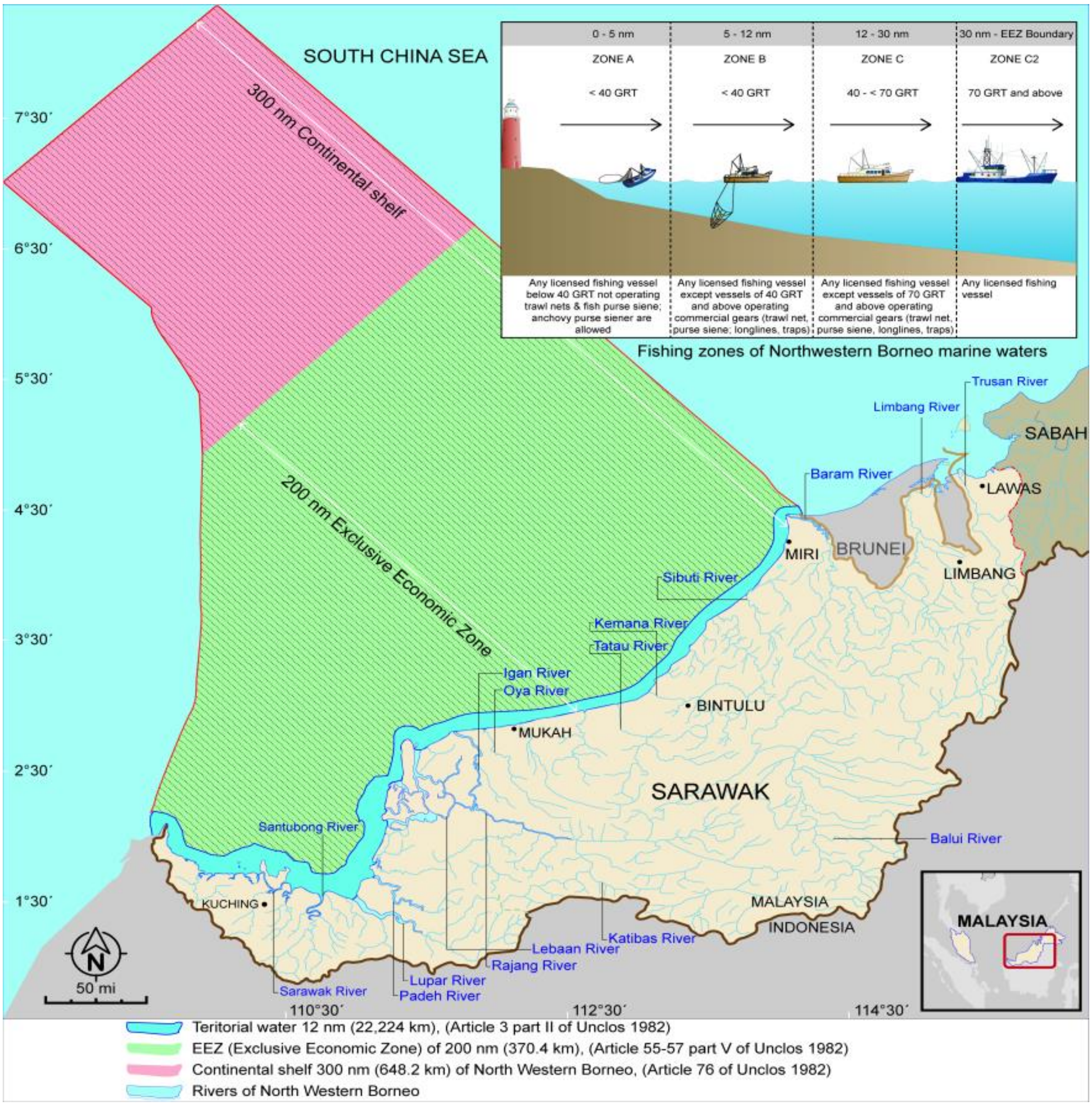

Figure 1. Common fishing areas of the northwestern Borneo waters, including the exclusive economic zone, territorial water and major rivers from where fisheries resources are exploited (Zahari & Zulkifli, 2021)

Species Vulnerable to Extinction (V_i)

The category of species vulnerable to extinction (Vi) was determined at two stages: species were classified as vulnerable to extinction in the first stage if they were listed under the IUCN list of threatened species (Critically Endangered, Endangered, and Vulnerable) (IUCN, 2017). Species that were not included in the threatened group based on the IUCN status (Near Threatened, Least Concern, Data Deficient, and Not Evaluated), were then re-evaluated according to their V_i at the second stage. Only species recorded as "very highly vulnerable" (V_i: 75-100) were included in our review as vulnerable species to extinction. The validity of V_i as a reliable indicator of species vulnerability to extinction was confirmed through the correlation between IUCN status and V_i, using SAS software version 9.4. IUCN reports to the lowest taxonomic level of species, and intrinsic vulnerability, as included in the validity analysis, was estimated with the fuzzy logic expert system documented by Cheung *et al.* (2005). Since the V_i of species increases with vulnerabilities, scores were presented using the IUCN status code to facilitate performing statistical tests: Data Deficient (1), Least Concern (2), Near Threatened (3), Vulnerable (4), Endangered (5), and Critically Endangered (6).

RESULTS AND DISCUSSION

Checklist and Present Status of Fishery Resources in Sarawak

About 564 species of fishery resources from 32 orders and 123 families are documented in Sarawak (NorthWest Borneo), Malaysia. Among the 32 orders, Perciformes (148 sp.) comprised a higher number of species, followed by Cypriniformes (130 sp.), Siluriformes (77 sp.), while the rest of the orders had less than 50 species. The comprehensive checklist also suggested that order Perciformes (44 families) comprised the highest number of families compared to the other orders (Figure 2).

Of these, each of the eight families has more than 15 species, namely Cyprinidae (82), Balitoridae (34), Bagridae (21), Penaeidae (21), Gobiidae (19), Siluridae (19), Carcharhinidae (16), and Engraulidae (16). Freshwater species comprised the majority of the fish community (271 species, 48.0%), followed by a marine (206 species, 36.6%), marine-euryhaline (73 species, 12.9%), and brackish-water species (14 species, 2.5%) (Figure 3).

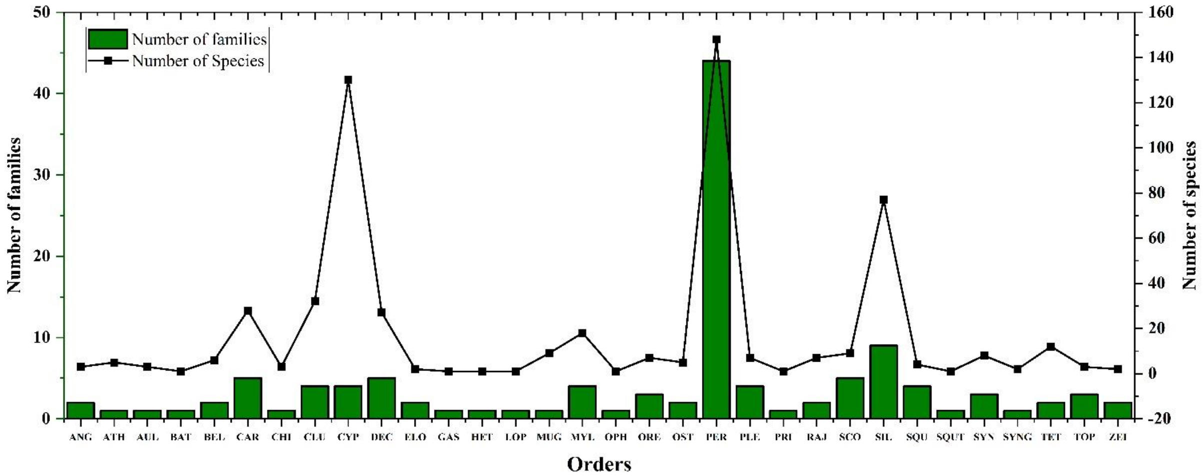

Figure 2. Number of fish species and families based on orders in Sarawak (ANG-Anguilliformes; ATH-Atheriniformes; AUL-Aulopiformes; BAT-Batrachoidiformes; BEL-Beloniformes; CAR-Carcharhiniformes; CHI-Chimaeriformes; CLU-Clupeiformes; CYP-Cypriniformes; DEC-Decapoda; ELO-Elopiformes; GAS-Gasterosteiformes; HET-Heterodontiformes; LOP-Lophiiformes; MUG-Mugiliformes; MYL-Myliobatiformes; OPH-Ophidiiformes; ORE-Orectolobiformes; OST-Osteoglossiformes; PER-Perciformes; PLE-Pleuronectiformes; PRI-Pristiformes; RAJ-Rajiformes; SCO-Scorpaeniformes; SIL-Siluriformes; SQU-Squaliformes; SQUT-Squatiniformes; SYN-Synbranchiformes; SYNG-Syngnathiformes; TET-Tetraodontiformes; TOP-Torpediniformes; ZEI-Zeiformes)

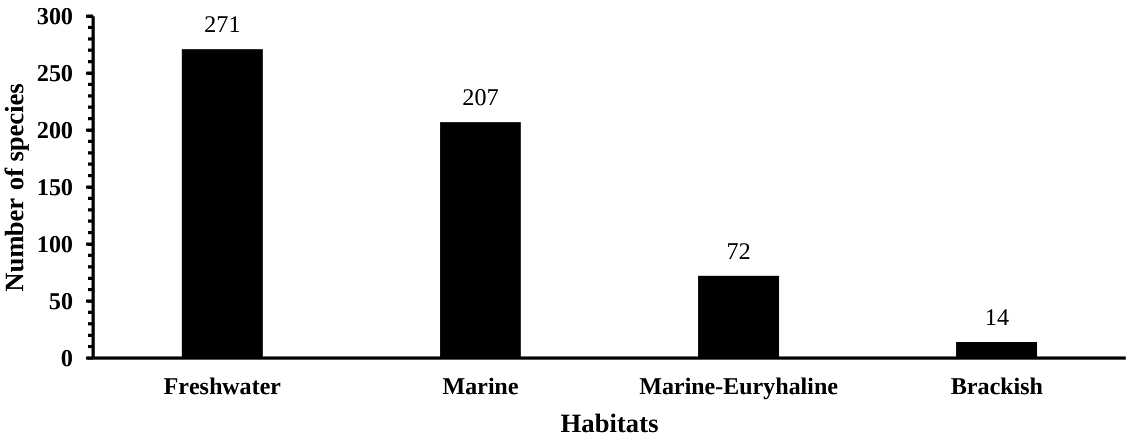

Figure 3. Fish number based on habitats in Sarawak waters

Out of the total fish species compiled in this review, 528 species (93.6%) have been reported to the lowest taxonomic level of species. The remaining species were described up to the taxonomic level of genera (29 species), family (1 species), or resemblance of species (7 species denoted “cf”) (Table S1).

The major fishes in Sarawak water bodies, 445 species representing 79% of total species, are native to Malaysia. This includes the presence of 41 possibly native species to Malaysia that have never been reported on Fishbase or Sealifebase websites (Figure 4).

Endemic fishes are vulnerable to environmental changes (Chong *et al.*, 2010) were also documented. A total of 15 endemic species were recorded in Sarawak water bodies, in which eight species belong to the *Gastromyzon* genus endemic to the Island of Borneo. According to Hadiaty (2017), *Gastromyzon* fishes are susceptible to habitat alteration due to their impaired ability to swim, making them highly isolated and restricted to single watersheds (Chong *et al.*, 2010). The number of endemic species recorded in Sarawak in the current review was lower than the 19 species reported previously by Chong *et al.* (2010). This resulted from the presence of *Gastromyzon fasciatus*, *G. megalepis*, *Hypergastromyzon eubranchus*, and *Neogastromyzon pauciradiatus* in Kalimantan, Indonesia (Froese & Pauly, 2017), which meant that they were not categorized as endemic species as determined by country, but have nonetheless been recorded as endemic to Sarawak in the current review.

In addition, the current study registered the presence of 20 alien species in Sarawak water systems, with 13 being introduced species. At the same time, another seven could be foreign species occurring in an expansion of the normal distribution ranges of those species. The introduced species reported in our literature review were from freshwater inhabitants brought into Sarawak for aquaculture and the aquarium trade. For example, *Helostoma temminckii*, an ornamental species reported to be native to Malaysia (Froese & Pauly, 2017), was recorded as an “introduced” species in the current study. Rahim *et al.* (2013) described this species as being native to Peninsular Malaysia but having been introduced for the aquarium trade in Sabah and Sarawak.

From the total number of species reported in our literature review, less than half (234 species, 41%) have been assessed by IUCN. Based on the IUCN Red Lists status, 31 species fell into the group of vulnerable to extinction, of which three were alien species (Figure 5).

The vulnerable alien species detected were *Pangasianodon hypophthalmus*, *Limulus polyphemus*, and *Rhynchobatus laevis*. The larger portion of vulnerable species reported in our study were marine inhabitants, composed mainly of sharks and rays. The most vulnerable species identified was *Pristis zijsron* (IUCN status: CR), followed by another 10 species classified as endangered: *Balantiocheilos melanopterus*, *Carcharhinus borneensis*, *Eusphyra blochii*, *Lamiopsis temminckii*, *Pangasianodon hypophthalmus*, *Pastinachus solocirostris*, *Scleropages formosus*, *Sphyrna lewini*, *S. mokarran*, and *Stegostoma fasciatum*.

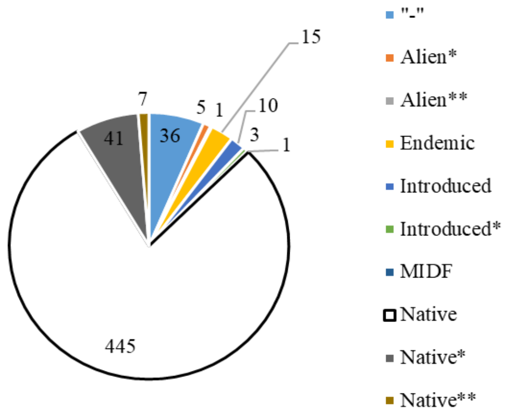

Figure 4. Occurrences of fishes available in Sarawak waters (coding refer to Table S1)

Assessment based on V_i showed that 30 species were vulnerable to extinction. This included four species that had not been evaluated by IUCN including *Wallago leerii*, *Muraenesox cinereus*, *Plotosus canius*, and *Sphyraena jello*, as well as three alien species: *Rhynchobatus laevis*, *Clarias gariepinus*, and *Pangasianodon hypophthalmus*. Also, out of 30 species, 13 were also grouped under vulnerable to extinction according to IUCN status. Similarly, to the IUCN results, the major portion of species examined by V_i as vulnerable to extinction were marine fishes.

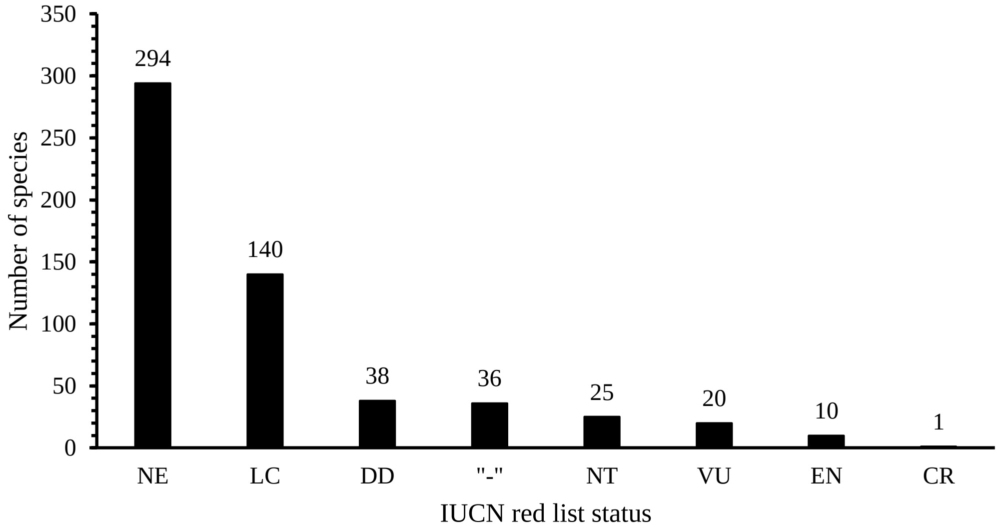

Figure 5. IUCN red list status of fishes available in Sarawak waters (Coding refer to Table S1)

Intrinsic Extinction Vulnerability Index as a Reliable Indicator of Species Vulnerability to Extinction

Pearson's coefficient analysis of data aggregated for 232 species of fish revealed that V_i was significantly correlated to the IUCN status of species (r=0.3487; p<0.0001; n=232). Furthermore, Cheung *et al.* (2005) recorded significant relationships between these two parameters using goodness-of-fit (p=0.0253; n=40). Therefore, it is concluded that V_i is a reliable indicator of species' vulnerability to extinction. Since more than half of the fishes (295 species, 52.3%) identified to the lowest taxonomic level in our review were not evaluated by IUCN, it is unwise to ignore their vulnerabilities simply. Hence, to determine the vulnerability of species to extinction, all species marked as near threatened (NT), least concern (LC), data deficient (DD), as well as those that have not been evaluated (NE) by IUCN, should be considered, or re-evaluated using the species V_i.

V_i is derived from a fuzzy logic expert system, that integrates the life history and ecological characteristics of fishes, and was first developed by Cheung *et al.* (2005) to estimate the vulnerability of marine fish species to fishing, by taking into account their maximum length, age at first maturity, longevity, von Bertalanffy growth parameter K, natural mortality rate, fecundity, strength of spatial behaviour, and geographic range. The vulnerability was expressed on an arbitrary scale from 1 to 100 and categorized into four levels of intrinsic vulnerability to extinction; namely, very high (75-100), high (50-74), moderate (25-49), and low (1-24) (Chong *et al.*, 2010). In this study, two valuation stages (IUCN and V_i estimation) indicated that 48 species in Sarawak water bodies are currently vulnerable to extinction.

Requirement for Fisheries Monitoring in Sarawak Waters

The detection of alien and vulnerable species and the presence of fishes that have not been reported or queried in Fishbase or Sealifebase websites needs further assessment. Based on the findings of our study, a total of 109 species that occurred in Sarawak water bodies should be monitored under proper fishery resource management. The occurrence of fisheries in Malaysia that have not been reported in Fishbase or Sealifebase accounted for the highest number of species (49 species), followed by those identified as vulnerable (48 species) and alien (20 species). In addition, nine species previously reported as "questionable" or "misidentification" in Malaysian water bodies require validation (Table S2).

The South China Sea included the greatest number of species that require further monitoring among all the specified locations. Thus, it is crucial, especially for the conservation of 32 vulnerable species that were found to be presented there. Additionally, monitoring emphasis should be given to the coastal waters off Bintawa, Mukah, and Kuching. In contrast, the Sarawak and Maong rivers should be assessed to evaluate the invasiveness of alien species in those water bodies (Table 1).

Table 1. Proposed monitoring locations in the water bodies of Sarawak (northwestern Borneo), Malaysia

No.	Location	No. of species			
		AL	VU	NRIF	QM
1	Batang Kerang, Balai Ringin, Serian	3	–	4	1
2	Bintulu/Similajau coastal area, Bintulu	–	1	1	–
3	Marudi	–	1	–	–
4	Nanga Merit, Kapit	–	–	2	–
5	Rajang basin	2	4	2	–
6	Rayu basin	–	–	2	–
7	Sadong basin	–	1	–	–
8	Semariang, Kuching	1	1	6	1
9	Sg. Akar	–	–	1	–
10	Sg. Baram/ Baram river system	2	–	2	1
11	Sg. Kuap	1	2	9	–
12	Sg. Lutong	2	1	4	–
13	Sg. Maong	7	2	3	–
14	Sg. Sarawak	10	3	10	–
15	Sg. Sibuti	2	3	2	1
16	South China Sea	2	32	8	2
17	Not specified	2	6	5	4

Note: AL=Alien species; VU=Vulnerable species; NRIF=Species occurrence in Malaysia that have not been reported in Fishbase or Sealifebase; QM=Species marked as 'questionable' or 'misidentification' in Fishbase or Sealifebase; Sg.= Sungai (River); '–'=Not applicable.

Occurrence and Management of Alien Species

The presence of alien species in natural water bodies can disrupt the ecological balance. However, there are currently no restrictions or limitations on the dispersal of alien species in natural habitats in Malaysia (Rahim *et al.*, 2013). Furthermore, any serious attempt to thoroughly monitor the establishment of alien fish or the potential threats to local biota and ecosystems in Malaysia is still lacking. Research conducted by Rahim (2012) is probably the most comprehensive study to date to evaluate the composition, ecology, distribution, and abundance of alien species across various habitats in Malaysia. Although Rahim (2012) and Froese & Pauly (2017) noted that it is still premature to suggest that the alien species have a significant impact on native fishes, their potential for damage reported to have occurred in other countries, its possible consequences should not be neglected.

Six of the identified alien species in this study have not been reported in Fishbase or Sealifebase websites; hence further assessment is urgently needed to confirm their occurrence, as well as the degree of their establishment in Sarawak waters. Fishes present outside of their distribution range, reported in this review, were mostly from marine water systems, except for freshwater species *Chitala chitala* and *Johnius gangeticus*, unlike the case with introduced species. It was reported that the occurrence of *C. chitala* (Clown knifefish) in Malaysia, and five other countries in Southeast Asia, could be a misidentification. The records from Malaysia and Indonesia were suspected to be of *C. lopis*, while those from Thailand and other Indo-Chinese countries could be *C. ornata* (Froese & Pauly, 2017). Despite the assumption that the record of *C. chitala* at the Baram river system in Sarawak was potentially a misidentification, future monitoring at the said location is essential to validate the species.

Johnius gangeticus (croaker fish) is a freshwater fish endemic to India often observed in river estuaries Froese & Pauly (2017). However, the occurrence of *J. gangeticus* in Sarawak as well as in other Malaysian water bodies was recorded for the first time by (Hoque *et al.*, 2015). In a study conducted at Sibuti river estuary, Hoque *et al.* (2015) reported the presence of 38 individuals of *J. gangeticus*. They described that this fish was the most prominent species caught with 4-inch mesh nets. Apart from *J. gangeticus*, Hoque *et al.* (2015) also reported a potential alien species of horseshoe crab called *Limulus polyphemus* in their study, which had not been previously reported found in Malaysian water bodies. *Limulus polyphemus*, commonly known as American horseshoe crab, is one of four species of horseshoe crabs described in the world. This species is distributed along the Atlantic coastline of North America, ranging from the Yucatán Peninsula, México to the Gulf of Maine, USA (Smith *et al.*, 2016). The remaining three species of horseshoe crabs: *Carcinoscorpius rotundicauda*, *Tachypleus gigas*, and *T. tridentatus*, inhabit the coastal waters of Asia, from India to Japan (Smith *et al.*, 2016), including Malaysia (Christianus & Saad, 2009). In Malaysia, the horseshoe crab is locally known as “Belangkas”.

The occurrence of *Orectolobus maculatus*, *Rhynchobatus laevis*, and *Pseudocaranx dentex* was outside of the distribution ranges of the species, and their presence in Malaysia water bodies has not been reported in Fishbase. The former two species were found in the South China Sea (Yano *et al.*, 2005), while *P. dentex* was observed in Semariang mangrove area in Kuching (Nyanti *et al.*, 2012a). *O. maculatus* (Spotted wobbegong) is a species of shark distributed along the Eastern Indian Ocean, from Western Australia to Southern Queensland, and is reported to be endemic to Australia (Last & Stevens, 1994; Huveneers *et al.*, 2015; Froese & Pauly, 2017). This species can be found on the continental shelves, commonly on coral and rocky reefs, coastal bays, estuaries, seagrass beds, under piers, and sandy bottoms. In Australia, this shark has been mistakenly identified as *O. halei* and *O. parvimaculatus*. The records of this species from Japan and the South China Sea could also be a misidentification, possibly *O. japonicus* (Japanese wobbegong), or other undescribed species from the family of Orectolobidae (Tanaka *et al.*, 2009).

Rhynchobatus laevis (Smoothnose wedgefish) is a benthic species of elasmobranch that usually occurs near the coast in shallow bays, and off river mouths. This fish can be found in the Indo-West Pacific, from Oman to Japan, and is reported to be native to 12 countries (Froese & Pauly, 2017). *Rhynchobatus laevis* is often confused with *R. djiddensis* (Giant guitarfish) and *R. australiae* (Bottlenose wedgefish) (Compagno & McAuley, 2016), of which the latter species is native to Malaysia (Froese & Pauly, 2017). *Pseudocaranx dentex* (White trevally) is a commercially important pelagic fish, widely distributed across Western Atlantic, Eastern Atlantic, and Indo-Pacific (Froese & Pauly, 2017). The juveniles of this species inhabit bays, estuaries, and shallow continental shelf waters, whereas the adults usually form schools near the sea bed on the continental shelf (May & Maxwell, 1986; Kailola *et al.*, 1993; Smith Vaniz *et al.*, 2015; Froese & Pauly, 2017). In Sarawak, Nyanti *et al.* (2012a) collected one individual of *P. dentex* from Pergam Kecil River (Station 6), a river located farthest from the flood mitigation works at Semariang. This report was the only record of this species from Sarawak and to the best of our knowledge, the sole record for Malaysia waters and Southeast Asia.

Psenopsis shojimai can be found across the Northwest Pacific and is reported to be native to Japan. However, Fishbase marked the occurrence of this species in Malaysia as “Questionable” based on specimens collected from Sarawak waters (Mohsin & Ambak, 1996), due to its distributional range (Froese & Pauly, 2017). Because little is known about the distribution, biology, ecology, and threats to this species, the assessment of *P. shojimai* in Sarawak waters is urgently required to improve our current understanding of this species.

Species Vulnerability and Conservation Priority

Shark and Ray

The detection of 48 species of fishes vulnerable to extinction in Sarawak water bodies drives the critical need for future monitoring and conservation by scientists and relevant government bodies. Out of all vulnerable species, 33 species (68.8%) were composed of sharks and rays: *Aetomylaeus nichofii*, *Carcharhinus borneensis*, *C. galapagensis*, *C. leucas*, *C. plumbeus*, *Chaenogaleus macrostoma*, *Dasyatis thetidis*, *Eusphyra blochii*, *Glaucostegus typus*, *G. thouin*, *Gymnura zonura*, *Hemigaleus microstoma*, *Hemipristis elongata*, *Heterodontus zebra*, *Brevitrygon walga*, *Maculabatis gerrardi*, *Pateobatis uarnacoides*, *Himantura uarnak*, *H. undulata*, *Lamiopsis temminckii*, *Pastinachus solocirostris*, *P. sephen*, *Plesiobatis daviesi*, *Pristis zijsron*, *Rhinobatos formosensis*, *Rhynchobatus laevis*, *Sphyrna lewini*, *S. mokarran*, *Squatina tergocellatoides*, *Stegostoma fasciatum*, *Telatrygon zugei*, *Triaenodon obesus*, and *Urogymnus lobistoma*.

Nearly all of the vulnerable elasmobranchii documented in our review (31 species) were reported by Yano *et al.* (2005) from their six years of comprehensive study (1999-2004) of sharks and rays in Malaysia and Brunei Darussalam water bodies. In their study, Yano *et al.* (2005) recorded 74 elasmobranch species that landed in Sarawak waters and revealed that close to (50%) were vulnerable to extinction.

Global shark and ray catches increased steadily to a peak in 2003 and have since declined by at least 20% (Dulvy *et al.*, 2014). Dulvy *et al.* (2014) estimated that one in four elasmobranch species is currently threatened with extinction, particularly prevalent in the Indo-Pacific region. In Southeast Asia, for example, the depleted populations of sharks and rays have caused fishermen to travel much farther from the port to increase their catches (Chen, 1996). High demand for shark fin soup in the Asian market could be the primary driver of the overexploitation of sharks (Kyne *et al.*, 2016). The "fin trade" alone was reported to generate about USD 400-550 million annually (Clarke *et al.*, 2007), contributing to half of the total value of global shark fisheries (Dulvy *et al.*, 2017). In addition, extensive net and trawl fisheries have depleted the stocks of sharks and rays in Indonesia by at least an order of magnitude (Blaber *et al.*, 2009). Apart from overfishing, habitat loss and degradation could also magnify the extinction risk of these species, especially those inhabiting freshwater environments (Dulvy *et al.*, 2014). Since sharks are migratory, careful monitoring throughout their distribution ranges is urgently needed to ascertain their status and possible threats to these species.

In Malaysia, sharks and rays are not explicitly targeted but caught together with other commercially important fishes as retained bycatch. The total catches of elasmobranch increased from 10,792 tonnes in 1982 to 22,148 tonnes in 2012, contributing about 1.8% annually to the total marine landings (DoFM, 2014). Since the species are fully utilized in many parts of the country, the global issue of shark finning is not considered a problem in Malaysia (DoFM, 2014). Sharks are mainly consumed as fresh meat or processed as salted fish. In Sarawak, shark meat is usually made into a local delicacy called "umai" (DoFM, 2006).

Elasmobranch biodiversity studies in Malaysia were initiated in 1996 by the Shark Specialist Group and various government departments in the states of Sabah and Sarawak (Fowler *et al.*, 2002). In 2006, Malaysia established her first National Plan of Action for the Conservation and Management of Sharks (NPOA- Shark Plan 1), in accordance with the guidelines developed by FAO in the International Plan of Action for the Conservation and Management of Sharks (IPOA-Sharks) (DoFM, 2006). Malaysia was among the first countries in Southeast Asia to develop such a plan. This approach was then followed by the second NPOA-Shark (Plan 2), launched in 2014 to ensure continuous improvement of shark conservation and management in Malaysia (DoFM, 2014).

To protect and sustainably manage the fishery resources, restrictions have been imposed on several destructive fishing methods such as explosives, poisons, pollutants, electric shocks, paired trawls, and push nets under the Fisheries (Prohibition of Method of Fishing) Regulations of 1980, and in Section 26 of the Fisheries Act of 1985. Since 1990, Malaysia has also banned the use of "pukat pari", a drift net with a mesh size of more than 25.4 cm (10 inches), which was once used to catch large-sized sharks and rays. Moreover, *Rhincodon typus* (Whale shark) and seven species of sawfish have been listed as endangered marine animals in Malaysia under the Fisheries (Control of Endangered Species of Fish) Regulations of 1999. The regulations stipulate that no person shall fish, disturb, harass, catch, kill, take, possess, sell, buy, export, or transport any endangered species of fish, including their parts, except with the written permission from the Director-General of Fisheries Malaysia (DoFM, 2014). Recently, Sabah and Sarawak governments proposed the protection of another seven species of Elasmobranchii under regulations. These five shark species were: *Sphyrna lewini* (Scalloped hammerhead), *S. mokarran* (Great hammerhead), *S. zygaena* (Smooth hammerhead), *Eusphyra blochii* (Winghead shark), *Carcharhinus longimanus* (Oceanic whitetip shark), and two species of ray: *Manta birostris* (Giant manta) and *M. alfredi* (Alfred manta) (Borneo Post, 2016, 2017).

Based on current study findings, *Pristis zijsron* (Longcomb sawfish) is the most threatened species of elasmobranch, or fish ever reported in Sarawak. The landing of this sawfish was last reported in April 1981 from Sarawak waters, and it has since been described as locally extinct. The sole specimen was collected from the waters off Bintulu at a depth of 22-24 m by trawl net (Yano *et al.*, 2005). Despite its wide distribution, the population of *P. zijsron* has declined by more than 80% over the last three generations. The species has been listed in Appendix I of the Convention on the International Trade in Endangered Species (CITES), and is protected by no-take status in some of its range states (e.g., Australia, India, Bahrain, and Qatar) (Simpfendorfer, 2013). Apart from *P. zijsron*, another species of sawfish suspected to be *P. pristis* (Largetooth sawfish) was caught by fishermen from the sea near Pulau Bruit, Daro in June 2014. The sawfish was almost 300 kg, 5 metres long, and 2 metres wide (Borneo Post, 2014). Before the landing of *P. pristis* from Sarawak water, IUCN noted that this species was possibly extinct from Malaysia waters (Kyne *et al.*, 2013). Since the occurrence of *P. pristis* has never been scientifically documented, the species has not been included in the current review checklist. More research is needed to confirm the presence of these sawfish species in Sarawak waters.

Some species of vulnerable shark and ray, reported in our review, are probably more susceptible to extinction than the remainder due to their restricted distribution ranges, such as applies to *Carcharhinus borneensis* (Borneo shark), *Urogymnus lobistoma* (Tubemouth whipray), *Pateobatis uarnacoides* (Whitenose whipray), *Pastinachus solocirostris* (Roughnose stingray), and *Rhinobatos formosensis* (Taiwan guitarfish). *Carcharhinus borneensis* is a rare species of shark that has not been recorded since 1937 (Compagno, 2009), but was rediscovered by Yano *et al.* (2005) at a fish market in Mukah, Sarawak, during their elasmobranch study. High commercial values of *P. uarnacoides* skin, and *R. formosensis* fin have driven the over-exploitation of these species (Compagno *et al.*, 2006; White *et al.*, 2016a). Coastal and mangrove destruction could further increase extinction risk for these species, especially those highly dependent on such habitats like *U. lobistoma* and *P. solocirostris* (Fahmi *et al.*, 2009; Manjaji-Matsumoto *et al.*, 2016).

Elasmobranchii inhabiting or dependent on freshwater is more vulnerable than those living solely in the marine ecosystem (Dulvy *et al.*, 2014), possibly due to direct exposure to water pollution and habitat modification. *Carcharhinus leucas* (Bull shark), for example, migrate far upriver for breeding and are among sharks that can tolerate the longest period of time in freshwater (Simpfendorfer & Burgess, 2009). In addition, some species live and breed permanently in freshwater, like *Glaucostegus typus* (Giant shovelnose ray). *Glaucostegus typus* is regarded as one of the most economically valuable Elasmobranchii, mainly because of the attractive price paid for the fins (White & McAuley, 2016).

In this study, many sharks and rays are classified as vulnerable to extinction based on their life history, ecological characteristics, and intense fishing pressure on the species. They are *Brevitrygon walga* (Scaly whipray), *Telatrygon zugei* (Pale-edged stingray), *Pastinachus sephen* (Cowtail stingray), *Plesiobatis daviesi* (Deep-water stingray), and *Triaenodon obesus* (Whitetip reef shark). Despite having low commercial value because of their relatively small sizes, *B. walga* and *T. zugei* have been caught in large numbers throughout their distribution ranges (White, 2016; White *et al.*, 2016b). *Pastinachus sephen* is highly valued for its skin. This has driven some fishermen in Kalimantan, Indonesia, to directly target this species in the bottom longline fishery (Fahmi & Manjaji, 2009). Froese and Pauly (2017) commented that *P. sephen* is currently in danger of extinction. Future expansion of deepwater fisheries could pose a significant threat to *P. daviesi* because of its rare population and poor resilience to exploitation (White *et al.*, 2015). *Triaenodun obesus*, on the other hand, is highly vulnerable to future fishing pressure and lack of management, mainly due to its restricted range of habitat. This species was closely associated with coral reefs and can usually be found in caves (Smale, 2005).

Other than Elasmobranchii, five species of fishes inhabiting marine/marine-euryhaline environments are also susceptible to extinction. These include *Caranx ignobilis* (Giant trevally), *Limulus polyphemus* (American horseshoe crab), *Muraenesox cinereus* (Daggertooth pike conger), *Plotosus canius* (Gray eel-catfish), and *Sphyraena jello* (Pickhandle barracuda).

Although these species are heavily exploited throughout their ranges, only *L. polyphemus* has been categorised as vulnerable by IUCN, whereas *M. cinereus*, *P. canius*, and *S. jello* have not been evaluated. *Caranx ignobilis*, on the other hand, was reported as Least Concern, but the life history and ecological characteristics of this species reveal otherwise.

Muraenesox cinereus, *P. canius*, and *S. jello* are essential fish and currently suffer from heavy fishing pressure. Although they are currently somewhat neglected by IUCN, the vulnerability of these species to extinction has received attention from some countries. For example, *M. cinereus* and *P. canius* have been listed as threatened fish in India (Mukhopadhyay, 1994; Mijkherjee *et al.*, 2002; Menon, 2004). Besides, *P. canius* has also been classified as vulnerable in Bangladesh (Hossain & Alam, 2015). In Malaysia, *P. canius*, locally known as "*Sembilang*", is one of the country's most commercially important food fishes (Leh *et al.*, 2012; Usman *et al.*, 2013). Anglers have reported population declines of this species in Tanjung Tokong, Penang (Sinar Harian, 2016); hence future monitoring is urgently needed to verify the current status of *P. canius* in Sarawak waters. *Sphyraena jello*, in contrast, is rather particular with its diet (Bachok *et al.*, 2004), feeding mainly on fish and occasionally squid. Its diet selectivity could be an added factor toward the future extinction of this species.

Freshwater Species

A total of 10 species of fish inhabiting Sarawak freshwater ecosystems are also threatened with extinction risk if no proper management plans are taken anytime soon to conserve them. These include three species endemic to Borneo: *Betta macrostoma* (Spotfin betta), *Encheloclarias prolatus*, and *Rasbora ennealepis*. Endemic species have long evolved and adapted to specific environmental conditions, and hence are more vulnerable to ecological changes such as habitat destruction, human disturbance, and water pollution (Chong *et al.*, 2010). In Sarawak, the occurrence of *B. macrostoma*, commonly known as Brunei Beauty, was observed in the northern part of the State around Marudi (Tan & Ng, 2005). *Betta macrostoma* is a highly sought-after fish in the aquarium trade. Due to its decreased population in the wild, Brunei Darussalam declared *B. macrostoma* a protected species and has banned any illegal possession and trade of this fish. However, no known conservation effort has been initiated to protect this species in Sarawak. At present, *R. ennealepis* has been reported only from the Rajang and Kapuas basins. Little is known about the biology of this fish; however, its restricted extent of occurrence and reduced habitat quality could pose significant threats to the species (Jenkins *et al.*, 2009).

Encheloclarias prolatus is a fish endemic to Sarawak. This species is only recorded in the peat swamp forest of Sadong basin, Serian (Chong *et al.*, 2010; Giam *et al.*, 2012). Giam *et al.* (2012) projected that *E. prolatus* has a 99% probability of becoming extinct by 2050 under the business-as-usual (BAU) scenario. Despite being highly vulnerable, very little is known about this fish. The V_i of this species (V_i = 10) was strongly contradicted by the susceptibility potentials described by IUCN and Giam *et al.* (2012). This observation could be due to a lack of information regarding the life history of *E. prolatus*; thus, future monitoring of this species is beneficially needed to fill the knowledge gap.

In addition, five freshwater fish native to Southeast Asia, identified in our study, are also in danger of extinction: *Balantiocheilos melanopterus* (Tricolor sharkminnow), *Chitala lopis* (Giant featherback), *Phalacronotus apogon*, *Scleropages formosus* (Asian bonytongue), and *Wallago leerii* (Giant Malayan catfish). *Balantiocheilos melanopterus*, locally known as "*Hangus*", has become rare or extinct in many river basins throughout its ranges (Froese & Pauly, 2017). In Malaysia, it has been recorded as locally extinct (Chong *et al.*, 2010) and is currently protected under the Fisheries (Control of Endangered Species of Fish) Regulations of 1999. Naturally uncommon fish like *C. lopis* (Vidthayanon, 2012), locally known as "*Belida*", could also become extinct with overfishing and habitat degradation. A similar event may happen to the important food fish, *P. apogon*, since the young individuals are also caught for ornamental export (Ng, 2012). *Scleropages formosus* is a highly important ornamental fish and has been targeted by the aquarium trade since the 1970s, leading to population declines in the wild, made worse by habitat degradation caused by various human activities. The population of *S. formosus* has decreased at an alarming rate in Malaysia waters.

This species has been listed in Appendix I CITES, and was recently described as nearly extinct from the wild (Ng, 2016).

Wallago leerii, locally known as Tapah, is another important and popular food fish in Southeast Asia. So far, *W. leerii* has not been evaluated by IUCN. However, based on its life history and ecology, the vulnerability of this species to extinction should not be ignored. This fish used to form large migratory schools along Kapuas, Indonesia, but such schools have become less noticeable over time (Kottelat & Widjanarti, 2005; Froese & Pauly, 2017). The occurrence of *W. leerii* was once recorded in Singapore waters by Haig (1950) but has probably since gone extinct (Ng, 1992). Apart from the Rajang basin, this species was also observed in the fish market near Sadong River, Serian (Ng, 1992); this was most likely collected from nearby water bodies. More research is required to assess the present status of *W. leerii* in Sarawak, particularly in large rivers such as in the Rajang and Sadong basins.

Changing Land Uses in Sarawak - Implications for Fishery Management

Any changes in land use can affect aquatic ecosystems, including alteration in water quality and habitat modification, leading to reduced fishery resources (Stobutzki *et al.*, 2006). Globally, 65% of river habitats are currently moderately or highly threatened due to changing land uses (Vörösmarty *et al.*, 2010). The primary land use change accountable for tropical deforestation is converting forests to agriculture (Geist & Lambin, 2002). More than 14% of the total land area has been converted to the industrial plantation in Sarawak, particularly for oil palm cultivation (Gaveau *et al.*, 2016). Forest conversion to oil palm plantations is more detrimental to biodiversity than logging. For example, significant changes in species composition and marked reductions in both taxonomic and functional diversity of organisms were observed following forest conversion to oil palm plantations in eastern Sabah (Edwards *et al.*, 2014). However, a worse impact on biodiversity could be seen from converting forests for agriculture on peatland.

Peatland

Peatland represents 13% (1.66 million ha) of the total land area in Sarawak (Lulie *et al.*, 2002). Despite its poorly buffered and highly acidic water content (~pH 3) (Posa *et al.*, 2011), as well as low concentrations of dissolved oxygen (Beamish *et al.*, 2003), peat swamp (also known as blackwater) supports several freshwater fish species, stenotopic to the hostile environment (Giam *et al.*, 2012; Sule *et al.*, 2016). A total of 40 species of fish were found inhabiting the blackwater streams in Sarawak, which accounted for about 20% of the total ichthyofauna of the peat swamp forests (PSF) in Malaysia (Sule *et al.*, 2016). However, deforestation and peatland conversion for agricultural purposes, particularly for oil palm cultivation, pose extinction risk to the fish inhabiting the region. Giam *et al.* (2012) projected that 16 species of stenotopic fish would become globally extinct by 2050 should PSF conversion in Malaysia and Indonesia continue at current rates. Out of the ten most vulnerable species specified, four can be found in Sarawak water bodies: *Betta ibanorum*, *Encheloclarias prolatus*, *Parosphromenus allani*, and *Sundadanio margarition*. Additionally, the former two species are also endemic to Sarawak.

Apart from being detrimental to biodiversity, large-scale peatland conversion will rigorously impact the Earth's climate (Giam *et al.*, 2012). The PSFs in Malaysia and Indonesia alone store 67 gigatons of carbon in peat, accounting for about 75% of the total tropical peat soil carbon storage globally (Page *et al.*, 2011). High temperatures resulting from carbon emission into the atmosphere will further enhance the decomposition rate of peat and consequently decrease biodiversity (Hooijer *et al.*, 2015). Furthermore, peatland deforestation can also increase the vulnerability of a region to flood. For example, in Rajang Delta, Sarawak, Hooijer *et al.* (2015) predicted that 72.9% of the area will be flooded by 2059 if peatland degradation remains at the current trend. Flood events combined with peatland destruction and global warming will drive changes in species composition or in the worst-case scenario, cause extinction of species.

Forest

Sarawak forests are also heavily subjected to logging activity, whereby the degradation occurs at 0.64% annually (Hon & Shibata, 2013). As of June this year, Sarawak has contributed about 28% of the total timber exports in the country (MTIB, 2017). Ling *et al.* (2016) revealed that logging activities deteriorate water quality in Sarawak forest streams, particularly during rainfall events. This effect includes significant temperature variation, sedimentation, and organic pollution due to canopy removal (Ling *et al.*, 2016), which could be deleterious to the aquatic inhabitants downstream. The actual situation may be worse since some logged forests in Sarawak are exploited illegally (Gaveau *et al.*, 2014).

Mangroves

Mangroves, woody plants that usually grow along the river banks, estuaries, and coastal areas, are highly productive and valuable ecosystems in the tropics. Apart from their ecological roles in seashore protection, carbon sequestration and storage, and filtration and assimilation of pollutants, mangroves are integral components of fisheries (Abu Hena *et al.*, 2020a; Abu Hena *et al.*, 2020b). Mangrove forests act as nurseries, feeding and breeding grounds, and providing shelter for a variety of fishes. In addition, they are also essential contributors of detritus to aquatic food webs (Faridah-Hanum *et al.*, 2019). Human activities have, however, heavily degraded the mangrove ecosystem. Malaysia and Indonesia, for example, lost about 30% of their mangrove forests between 1980 and 2005 through conversion of land to shrimp farms and salt pans, logging activity, and coastal development (FAO, 2007). If not managed properly, these human activities may negatively impact the water quality and the biodiversity, particularly the aquatic inhabitants in the mangrove forests.

Sarawak has the second-largest amount of mangrove forests in terms of area in Malaysia, representing about 26% (126,400 ha) of the total mangrove cover in the country (Faridah-Hanum *et al.*, 2019). Mangrove forests cover about 1.4% of the whole state land and occupy approximately 60% of the 740 km coastline. In Sarawak, mangrove forests can be found mainly along the sheltered shores and estuaries around Kuching, Sri Aman, Limbang, and Rajang Delta (PERKASA, 2009; Paul, 2010). Despite their well-known ecological functions, only about 48% of the mangrove forests in Sarawak have received conservation attention and are presently categorized as permanent forest reserves (Faridah-Hanum *et al.*, 2019).

A study conducted by Nyanti *et al.* (2012a) at Semariang mangrove area demonstrated the effect of multiple land use activities, i.e., construction of a flood mitigation channel, temporary human settlement, and sand mining, on the water quality. In their study, Nyanti *et al.* (2012a) reported that most of the measured physicochemical parameters of water were well below the Class E standard of the Malaysia Marine Water Quality Criteria and Standard (MMWQCS). The levels of dissolved oxygen recorded in their study were categorized as hypoxic (< 3.78 mg/L) and potentially deleterious to fish. Conversely, research carried out in Awat-Awat Lawas Mangrove Forest Limbang showed that the water quality in the area fell under Class III (moderate) based on the Malaysian Water Quality Index (MWQI) (Gandaseca *et al.*, 2014).

Dams

Another changing land-use issue in Sarawak is the construction of hydroelectric power dams. Sarawak has a high potential for hydroelectric power generation because of the high rainfall intensity, and ample availability of suitable sites for dam construction (SIWRS, 2008). Concerning this, under the Sarawak Corridor of Renewable Energy (SCORE) for economic growth and development, Sarawak plans to build 12 additional mega-dams under The Borneo Project 2015. Lee *et al.* (2012) reported that the water quality in the Bakun Hydroelectric Dam reservoir was acidic (pH < 6.0) and had high turbidity due to the inflow of suspended solids from upstream. The reservoir also contained a low concentration of dissolved oxygen (Lee *et al.*, 2012), which could be detrimental to aquatic species inhabiting the water bodies. Before the completion of Bakun Hydroelectric Project, Parenti and Lim (2005) projected that the dam construction might have a devastating effect on ichthyofauna in the area and lead to widespread extinction of species. One of the reasons could be disruption in the life cycle, particularly migratory species (Chong *et al.*, 2010). A recent study conducted by Gaveau *et al.* (2016) showed that approximately 83,362 ha of forest had been permanently flooded following Bakun and Murum power dams in Sarawak, between 2011 and 2014. Additionally, bioaccumulation of trace metals, particularly mercury, detected in dam impoundments could pose a health threat to humans through fish consumption (Sim *et al.*, 2014).

Fisheries in Sarawak could also be degraded due to the construction of flood mitigation channels using acid sulfate soils. Nyanti *et al.* (2012a) reported that flood mitigation channels in the Semariang mangrove area in Kuching, Sarawak could destroy the mangrove ecosystem and alter fisheries diversity due to large fluctuation in salinity from potentially potential large input of freshwater into the mangrove areas once the flood mitigation work is completed. During their study, Nyanti *et al.* (2012a) observed lower fisheries diversity, reduced concentrations of dissolved oxygen, and significantly higher total suspended solids at the stations located near the construction of flood mitigation channels.

CONCLUSION

A total of 564 species of fishery resources belonging to 123 families and 32 orders were recorded from the northwestern water areas of Borneo (Sarawak). Approximately 50% of these were from freshwater inhabitants (271 species), followed by a marine (207 species), marine-euryhaline (73 species), and brackish-water (14 species). Of this, Cyprinidae was the dominant group, followed by Balitoridae, Bagridae, Penaeidae, Gobiidae, Siluridae, Carcharhinidae, and Engraulidae. The present study revealed that 48 species of fish in Sarawak are currently vulnerable to extinction. This highlights the need for future monitoring and the initiation of appropriate conservation measures from the authorities. The occurrence of 20 alien species in Sarawak natural water bodies poses potential threats to the native fish and ecosystem; hence a proper management plan should be developed to prevent the increase of invasiveness. Additionally, future fishery monitoring in Sarawak should focus on the coastal waters off Bintawa, Mukah, and Kuching to manage vulnerable species; and the Sarawak and Maong rivers for the management of alien species.

Current changing land uses in Sarawak have caused habitat destruction and pose significant challenges to future fishery management in Sarawak. Our review described seven land use issues: forest degradation, agricultural expansion, peatland deforestation and conversion, logging, destruction of mangrove forests, construction of hydroelectric power dams, and construction and operation of flood mitigation channels. To counter these issues, we recommend the application of ecosystem-based fishery management (EBFM) approach whenever practicable in managing the outstanding fishery resources of Sarawak.

Less than half of the fishery resources documented in our study have been assessed by the IUCN Red Lists of Threatened Species. This result indicates that the vulnerability of most fishes reported in this study has been somewhat neglected; hence more research is urgently required to evaluate the present threats to the specified species. Nevertheless, the current study found significant correlations between the V_i and the IUCN status of species, suggesting that V_i is a reliable indicator of species' vulnerability to extinction. Thus, it is recommended to use Vi, which can be extracted conveniently from the Fishbase website, to supplement the vulnerability information provided by IUCN red lists of threatened species through the two-stage valuation described in our study.

This article assesses Northwest Borneo (Sarawak) fisheries resources, conservation challenges, and habitat vulnerability of diverse species. Rapid infrastructural development modifies land use patterns, and pristine and undisturbed fisheries habitats are vanishing quickly. Local, federal, conservation agencies, think tanks, practitioners, biodiversity managers, and other stakeholders must work together to solve this problem. Existing legislation for maintaining biodiversity and fishery habitat are plenty, but adequate management and execution are crucial. Priority-based conservation utilising IUCN red list recommendations is a key tool for species selection. Ramsar sites, MPAs, regional and national parks will help safeguard ecosystems. Overall, a stringent strategy must be followed to safeguard Sarawak's fishing resources.

ACKNOWLEDGEMENTS

The authors thank the Sarawak Biodiversity Center (SBC) and the Forest Department (FD) of Sarawak for their cooperation during this study. The study was funded by a grant from Universiti Putra Malaysia; code: GP-IPM/2017/9538200, UPM/800/2/2/4 Grant Putra and Higher Education Malaysia, FRGS research grant code, 07-01-18-2044FR.

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