An overview of the status, trends and challenges of freshwater fish research and conservation in Malaysia

Ng C. Keat-Chuan[1]; Ooi P. Aun-Chuan[1]; Wong W.L.[1]; Khoo G.[1]*

Received: April 2016 Accepted: September 2016

Abstract

Freshwater fish biodiversity is a precious natural asset in terms of economic, cultural and scientific interest. And yet, the inland freshwater ecosystem in Malaysia is declining at a far greater rate than terrestrial ecosystems in the tropics. What happened, and what is being done to address the crisis? This paper extracts findings from the latest literature and explores overarching issues pertaining to freshwater ichthyology in Malaysia. Various schools of thought on biogeography and some basic data are first discussed to characterise Malaysia's fish species distribution and diversity. Subsequently, fish research and conservation concerns are explicitly raised and discussed to reveal concerns affecting the research movement and freshwater habitat quality. It is hoped that this short review provides vital information to consolidate and drive effective national policies and programs for safeguarding the country's freshwater fish biodiversity.

Keywords: Conservation, Biogeography, Ecosystem, Fish, Freshwater, Malaysia

1- Faculty of Science, Universiti Tunku Abdul Rahman, Jalan Universiti, Bandar Barat, 31900 Kampar, Perak, Malaysia.

*Corresponding author's Email: gideonkhoo@utar.edu.my

Introduction

Among vertebrate animals which totalled approximately 54,711 recognized species, by far, fishes form the largest category. Their numbers are expected to reach more than 32,500 valid marine and freshwater species within 515 families (Nelson, 2006). In general, roughly 11,952 species, or about 40% of fish species, occur exclusively in or most often in freshwater (Helfman *et al*., 2009).

Freshwater species is a typical term used to describe fishes that are found in inland streams, rivers, lakes and regions of weak brackish water. The term may also encompass diadromous species such as sturgeons which often spend their lifecycle between inland freshwater and the ocean. Among them, some can be classified as anadromous (e.g. salmon, herrings), which means they usually migrate at incredible distances to the rivers and spawn in freshwater although they spend most of their adulthood at sea. In contrast, there are some 225 species which are catadromous (e.g. Anguilla eels) (Nelson, 2006) and they spawn in the ocean but live in freshwater. There is also a group of fish species that can live freely between waters of various levels of salinity and they are classified as euryhaline species.

Many hypotheses have been proposed to rationalise species diversity at a wide range of habitats on spatial scales and they can be categorized into three major hypotheses. Firstly, MacArthur's (1969) "area" hypothesis suggests that species diversity increases when there are more surface areas to accommodate habitats and speciation processes. Secondly, Wright *et al*. (2003) and Evans and Gaston (2005) proposed a "productivity'' hypothesis that expects species richness to increase when there is more energy available. "Energy" in this context refers to the productive energy of solar that translates to the volume of plants and biomass resources available to species to feed on and inhabit. In general, the hypothesis proposes that energy variability in the environment affects the rates of metabolism, speciation and molecular evolution in species. Consequently, high energy areas promote faster speciation and evolution, thus more species can occur. Thirdly, Ricklefs (2004) proposed the "historical" hypothesis which explains that competition, predation and mutualism relationship among species over ecological time provides the drive for diversity patterns.

With regards to freshwater fishes, the "area" hypothesis seems to be plausible for explaining richness variability, namely species richness tends to increase in proportion to the size of the basin area (Eadie *et al.*, 1986; Rosenzweig 1995; Hugueny *et al*., 2010). Biogeographically, larger freshwater areas appear to host more genera and species, namely the Neotropical region (705 genera, 4,035 species), Oriental (440 genera, 2,345 species), Afrotropical (390 genera, 2,938 species), Palaearctic (380 genera, 1,844 species), Nearctic (298 genera, 1,411 species) and Australian (94 genera, 261 species) regions (Leveque et al., 2008) (Fig. 1).

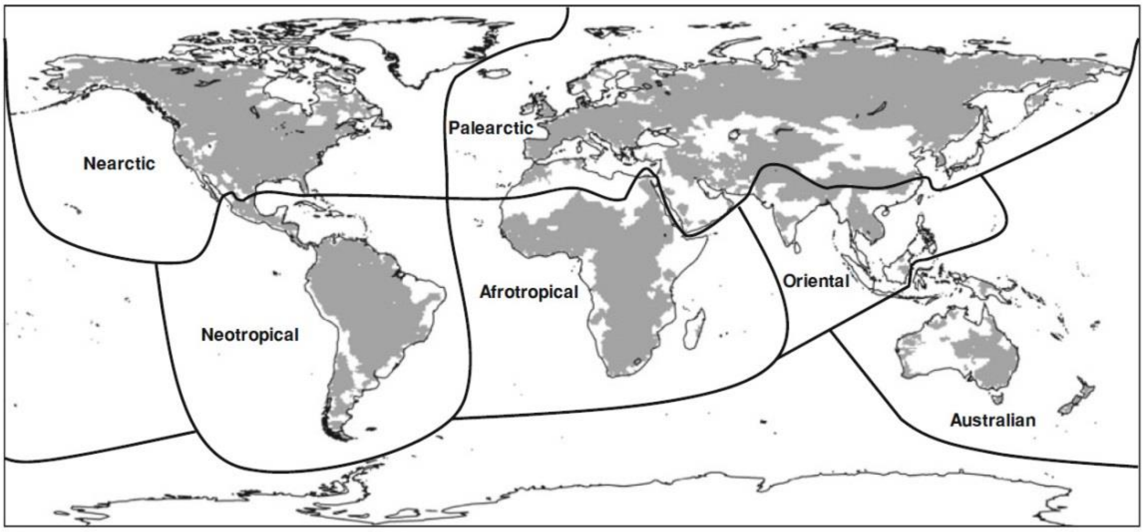

Figure 1: Major freshwater fish ecoregions encompassing 1,054 rivers as classified by the Fish-SPRICH database. Malaysia is located in the Oriental ecoregion. Source: Brosse *et al.* (2012).

What is the taxonomic composition of freshwater fishes in Malaysia?

Species richness increases with decreasing latitude and it is commonly known that there is a high level of endemism in the tropics. Malaysia is located in the Oriental tropical ecoregion that encompasses the east, south and southeast Asia regions. When combined, an estimated 3,500 freshwater fish species are present and high diversity occurs mostly in the equatorial countries with Indochina, India, Indonesia and Malaysia taking the lead. In comparison to Africa's 50 families and Latin America's 55 families, tropical Asia harbours a staggering 121 families within inland waters with cyprinids as the dominant group. The Mekong River basin hosts the highest diversity with 1,200 species followed by the Yangtze River basin in China and the Kapuas River in Indonesia with approximately 320 species each (Kottelat and Whitten, 1996).

Currently, the website http://ffish.asia/ website (Kano *et al.*, 2016) reports that there are 765 freshwater fish species found in Southeast Asia. In Malaysia, which encompasses peninsular and Sabah-Sarawak provinces, the online database FishBase (http://www.fishbase.org/search.php) (Froese and Pauly, 2016) has records for 634 species in Malaysia alone which are grouped into 68 families.

As indicated, the Cyprinidae family is the largest group (Fig. 2). The family encompasses 27.8% of fish species composition in Malaysia and with 33 species, *Rasbora* is the largest genus in the family (Froese and Pauly, 2016).

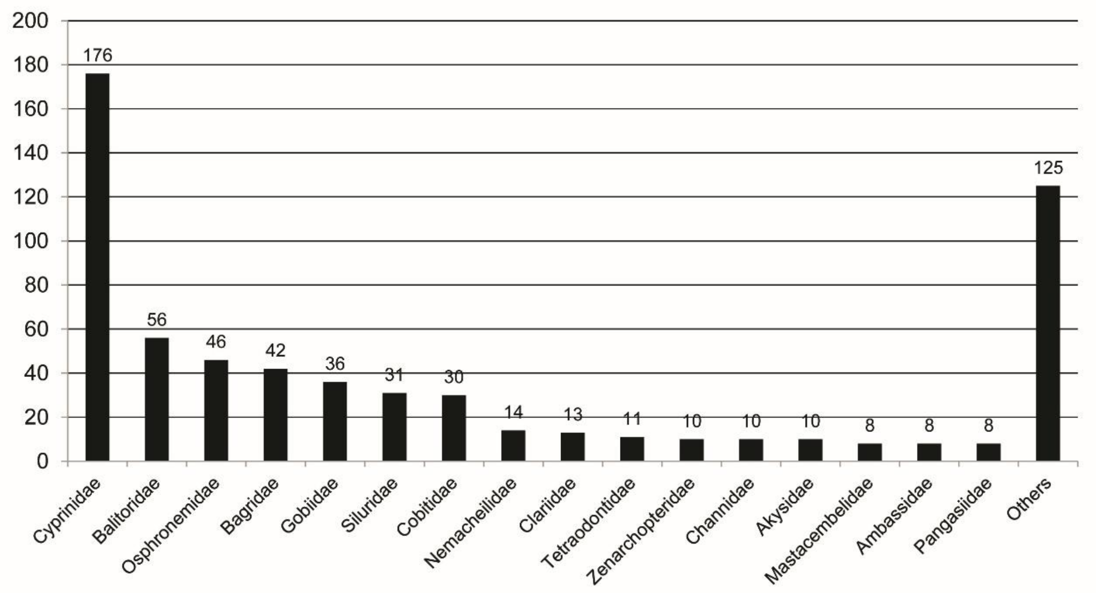

Figure 2: Major freshwater ichthyofaunal families in Malaysia. Source: Graph produced with data obtained from Froese and Pauly (2016).

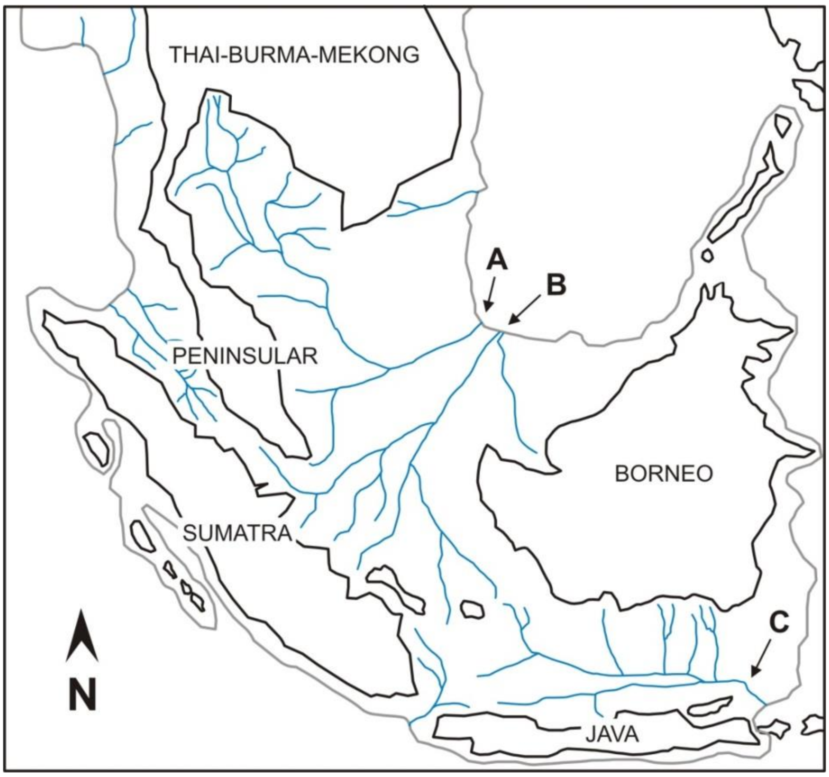

Figure 3: Major river networks in Southeast Asia during the Pleistocene era, namely East Sunda River (A), West Sunda River (B) and North Sunda River (C). Source: Adapted from Rainboth (1991).

Siluriformes is the most diverse order with 8 families of catfish and the *Hemibagrus* is the largest genus (Zakaria-Ismail, 1992). This numerical information can be taken as a guide when conducting field sampling in the freshwater habitats in Malaysia.

Also, to infer how many species can be hosted and typically found in a particular freshwater hydro-ecological unit, Ng and Tan (1999) reported that 108 species in 26 families were recorded in the Endau basin, which is located in the state of Johore. Such a large diversity is not unusual and this was observed by Johnson as early as 1967. He speculated that there is a pronounced difference in the fish distribution patterns between the north and south of Peninsular Malaysia (Fig. 4). Johnson observed that fish diversity is greater in the southern freshwater regions. He argued that the south has more acidic (pH<4) or brackish meso-habitats that harbour specialized tolerant species such as *Betta persephone*, *Parosphromenus tweediei* and striped barb (*Desmopuntius johorensis*). In the north, there are less brackish meso-habitats because they are typically dried out by the annual distinct dry weather during the period between the months of December to February (Wong *et al*., 2009).

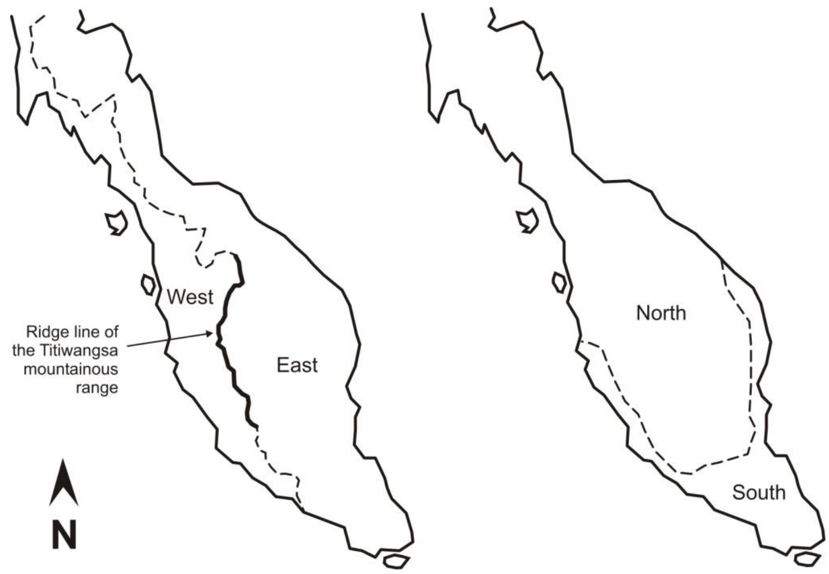

Figure 4: Comparison of the east-west faunal line (left figure) postulated by Abell et al. (2008) with north-southern crescent faunal line (right figure) suggested by Johnson (1967).

Another observation reported by Johnson (1967) is the dispersal pattern of cyprinids. In Malaysia, genera from the Cyprinidae family are diverse and productive in peat swamp and brackish waters such as *Rasbora* spp. and *Osteochilus* spp. However, in the Europe, cyprinids such as the white bream (*Blicca bjoerkna*), stone moroko (*Pseudorasbora parva*) and common rudd (*Scardinius erythrophthalmus*) typically populate hard waters (calcium content>60 mg/L) and leave acidic waters (pH<4) to other families (Johnson, 1967).

What is the ichthyofaunal biogeography pattern in Malaysia?

Biogeography is a science that is concerned with species vicariance (Wiley, 1988). Nelson and Paltnick (1981) describe it as "comparative biology of space, time and form". No matter how small a present watershed is, first and foremost, the broadest outlook of "space, time and form" should be investigated to understand ichthyofauna composition and niches for making decisions when conducting fish-based studies. Watersheds that occurred in the past but no longer exist at present day, typically known as paleo-drainage basins (Abell *et al*., 2008), and how they link the freshwater habitats at the alpha, beta and gamma diversity levels in the past should also be investigated (Jurasinski *et al*., 2009).

Alpha diversity is a term used to describe local diversity such as fish species composition in a stream or a river. The beta diversity encompasses fish diversity along a gradient for example, fish composition from the highland headwater to the lowland river. At the largest scale, gamma diversity refers to fish diversity at regional or watershed level. Regrettably, fish biogeography is not an active field of study in Malaysia. The subject is markedly riddled with knowledge gaps and literature is scarce. As mentioned earlier, politically Malaysia comprises the west (peninsular) and the east (Sabah and Sarawak) which are separated by the South China Sea. Any freshwater fish study in the country should include some local and regional fish biogeography investigation as part of the analysis process in order to produce a species presence or absence forecast in a particular target site. Such an approach would increase the robustness of the study (Abell *et al*., 2008).

During the Pleistocene epoch which occurred between 2,588,000 to 11,700 years ago, the northern peninsular might have a historical biogeographical link with the Thai-Burma-Mekong watershed systems while the watersheds in southern peninsular were linked to Sabah, Sarawak, Kalimantan, Sumatra and Java (Fig. 3) (Zakaria-Ismail, 1994; Voris, 2000; Bird *et al*., 2005; Abell *et al*., 2008; Hall, 2013). In a phylogeographic study where geographic distribution of species in southeast Asia were correlated with population genetics, Lohman *et al*. (2011) concluded that the Thai-Malay peninsula is the transition zone linking the Indo-Burmese and Sundaic regions. They also highlighted that Corner (1960) found that fishes in Riau-Palembang (Sumatra), Kapuas (western Borneo) and Johore River (southern peninsular Malaysia) to share the same haplotypes. To elaborate further, haplotype is a simplified term used to describe "haploid genotype". "Haploid" refers to cells with only one set of chromosomes and "genotype" refers to genetic makeup of a species (Kapuscinski and Miller, 2007). In fish species distribution studies, haplotypes offer important clues to reveal genetic similarity of individuals from different locations (Danzmann and Gharbi, 2001). Haplotype analysis by Kamaruddin and Esa (2009) on the tinfoil barb (*Barbonymus schwanenfeldii*) and Tan *et* *al*. (2012) who studied the common snakehead (*Channa striata*) population also supported the theory of historical biogeographical connection between the Thai-Burma-Mekong watershed systems in northern peninsular and that southern peninsular has a biogeographical linkage with Sabah, Sarawak, Kalimantan, Sumatra and Java.

In the context of peninsular Malaysia, Abell *et al*. (2008) took another approach to study fish biogeography. They established faunal lines in accordance to watershed delineation along the Titiwangsa mountainous range that runs from the northwest to the southeast of the peninsular (Fig. 4).

Abell *et al*. (2008) suggested that drainages which flow to the direction of Malacca Straits and South China Sea exhibit dissimilarity in fish composition. Correspondingly, they estimated that there are 150 species and 33 families in the west side of the Titiwangsa mountainous range which generally encompasses the inland and coastal plains of Perlis, Kedah, Perak, Selangor, Negeri Sembilan and Melaka states. For the east side of Titiwangsa mountainous range that generally covers Kelantan, Terengganu, Pahang and Johore states which are associated with the Thai-Burma-Mekong ecoregion, an exceptional 320 species and 43 families were estimated by them. The high species diversity is stark and this is demonstrated by examples such as the signal barb (*Labiobarbus festivus*), *Pseudomystus fumosus*, *Nanobagrus lemniscatus* and *Betta pi* which can only be found in the eastern side of Titiwangsa mountainous range (Roberts, 1993; Ng and Lim, 2005; Ng, 2010; Lee *et al*., 2012).

Since the island of Borneo is typically regarded as one ichthyofauna biogeography, the fish diversity in Sabah and Sarawak is expected to be rather similar to other regions in the 745,567 km^2 island. In Sarawak, Atack (2006) proposed that there are 254 species and in Sabah, Inger and Chin (2002) deduced that 168 species are present. Comparatively, a total of 263 species from 40 families and 120 genera were found in the Kapuas basin of Kalimantan (Roberts, 1989).

The freshwater biogeography boundary and subdivisions are still subjected to debates, primarily arising from the scarcity of data. As highlighted earlier, it is unfortunate that freshwater fish biogeography and the identification of fish species are not active fields of study in Malaysia as they are considered fundamental research with no economic returns.

What are the conservation and management status, trend and challenges?

Although ichthyofauna studies have been supposedly conducted for more than 160 years since Cantor (1849), freshwater fish conservation and taxonomy management in Malaysia is still considered in the discovery and exploratory stage (Zakaria-Ismail, 1992; Lim *et al*., 1993; Zakaria-Ismail, 1994; Ahmad and Khairul-Adha, 2005; Chong *et al*., 2010; Khairul, 2011). The lack of interest and funding constraints have also acutely affected ichthyological studies in the country although there are many unresolved taxonomic problems (Ahmad and Khairul-Adha, 2005). For instance, the Cyprinidae family is the largest in Malaysia but the systematics of its members has been historically convoluted especially those under the subfamily Cyprininae which is generally divided into four groups, namely barbins, cyprinins, labeonins and oreinins (Moghaddam *et al*., 2012). Within the barbin group alone, for example, *Puntiu*s which is the "catch-all" genus (Kottelat, 1999) is still problematic. In the past, a substantial number of small barbs have been assigned to the genus. Subsequently the species were taxonomically debated, revised and transferred to the *Barbodes*, *Barbonymus, Barbus, Capoeta*, *Hypsibarbus* and *Systomus* genera by the authorities progressively (Chen *et al*., 1984; Shantakumar and Vishwanath, 2006; Chen and Mayden, 2009; Kottelat and Tan, 2011; Collin *et al*., 2012; Kottelat, 2013), Since the *Puntius* genus encompasses a diverse range of species in Asian tropics and there are many researchers in various countries working with morphological and molecular methods, their nomenclatural validity is expected to remain unstable for a period of time (Pethiyagoda *et al*., 2012; Rajasekaran and Sivakumar, 2016).

Correspondingly, the status of the *Tor* genus under the Cyprinidae family is also somewhat unresolved for species that occur in Malaysia. According to various studies, the researchers have treated *Tor douronensis, T. tambra, T. tambroides,* and *T. soro* as valid species (Atack, 2006; Esa *et al*., 2006; Haryono, 2006; Ingram *et al*., 2007; Esa *et al*., 2008; Nguyen, 2008; Esa *et al*., 2012). At the time of this writing, the California Academy of Science's Catalog of Fishes website recognizes *T. douronensis, T. tambra and T. tambroides* as valid species. However, authorities such as Roberts (1999) and Kottelat (2013) noted that they could not explicitly distinguish morphological markers between the species. Therefore Kottelat (2013) has so far proposed that *Tor tambra* is the only valid species in Peninsular Malaysia, Sabah and Sarawak. The debate is expected to be prolonged as the taxonomic issue is complex.

Depository centres are the hearts of ichthyological science as obviously voucher specimens are needed for a solid foundation in conservation to ensure reproducibility in scientific method. Researchers are encouraged to preserve organism representatives in officially recognized and publicly accessible depositories so that these are available to peers at any time for examination, identification or when doubts arise. The permanent records or voucher specimens are also strictly labelled with geographical location and time they were collected to increase their value as scientific evidence. Nonetheless, for a country that hosts exceedingly rich biodiversity, it is unfortunate that Malaysia has yet to set up a national repository centre. At present, fish voucher specimens are scattered around the country (Table 1).

Table 1: Voucher specimen depositories for fish in Malaysia.

No.	Institution	Location and state
1.	Fisheries Research Institute (Freshwater Division)	Gelami Lemi, Negeri Sembilan
2.	Universiti Kebangsaan Malaysia (UKM)	Bangi, Selangor
3.	Kolej Universiti Sains dan Teknologi Malaysia (KUSTEM)	Kuala Terengganu, Terengganu
4.	Universiti Malaya (UM)	Kuala Lumpur
5.	Universiti Putra Malaysia (UPM)	Serdang, Selangor
6.	Universiti Sains Malaysia	Pulau Pinang
7.	Universiti Malaysia Sarawak (UNIMAS), Fish Museum	Kuching, Sarawak
8.	Natural History Museum	Kuching, Sarawak
9.	Likas Fisheries Research Center	Kota Kinabalu, Sabah
10.	Universiti Malaysia Sabah (UMS)	Kota Kinabalu, Sabah

Apart from the absence of a national repository as mentioned earlier, the predicament is compounded by frequent taxonomic revisions and there are insufficient ichthyologists in the country to work on resolving taxonomic issues (Zakaria-Ismail, 1992). Ahmad and Khairul-Adha (2005) also highlighted the scarcity of practising ichthyologists and that although many students are trained in the universities, they do not end up as active fish researchers.

In a comprehensive study of literature over a period of 20 years since 1987, Chong *et al*. (2010) estimated that 76% species were threatened mainly by habitat degradation, loss and modification. These include blackskin catfish (*Clarias meladerma*), pearl gourami (*Trichogaster leerii*) and all endemic species from the *Betta* genus. The bala shark *(Balantiocheilos melanopterus)*, *Encheloclarias kelioides* and *Neobarynotus microlepis* which are typically found in pristine rivers and wetlands are considered extinct in the wild. They also estimate that there are 144 threatened/extinct species, 81 endemic species and 26 introduced species in Malaysian brackish and freshwater habitats.

Rahim *et al*. (2013) highlighted that there were no serious attempts to study and manage the negative impacts of non-native species on native species composition although the non-native species such as Mayan cichlid (*Mayaheros urophthalmus*), Nile tilapia

(*Oreochromis niloticus*) and vermiculated sailfin catfish (*Pterygoplichthys disjunctivus*) have been recorded by many researchers for more than a few decades ago. It is also unfortunate that the production and release of fries of non-native species such as Java barb (*Barbonymus gonionotus*), sutchi catfish (*Pangasianodon hypophthalmus*) and grass carp (*Ctenopharyngodon idella*) into rivers and wetlands were significantly higher than native species for the past 40 years and ironically this was mainly carried out by the Department of Fisheries Malaysia (Khairul, 2011) as a measure to increase inland fishery productivity. Correspondingly, the latest water habitat trend likewise is not positive (Fig. 5).

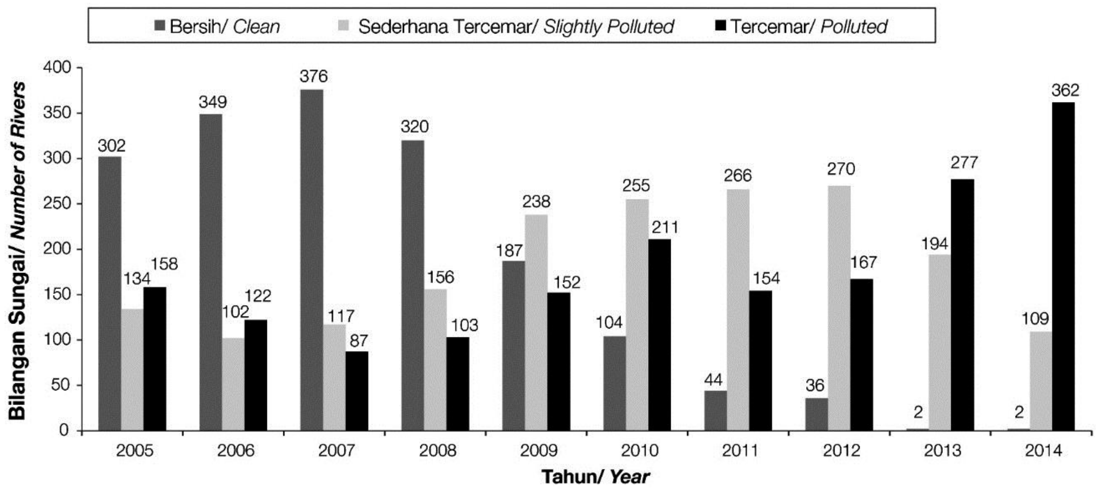

Figure 5: The number of "clean" rivers has been reduced drastically from 2005 to 2014 based on the Biochemical Oxygen Demand (BOD5) parameter tested. In 2014, only two rivers were classified as "clean". Source: Department of Environment, Malaysia (2014).

As the freshwater ecosystem is becoming more polluted, at some point, species extinction can be expected. Unfortunately, this would be unprecedented for Malaysia which is a tropical country that is endowed by a high level of biodiversity.

From our analysis, it is evident that the current "business-as-usual" approach has devastated many rivers in the country. The trend and evidence show that water-based habitats and natural resources are not managed and conserved in tandem with the country's rising fishery and freshwater security needs, and the situation is acute. Since there is also a lack of interest in fish taxonomy, species accounting in Malaysia is still very much in the discovery phase. Hence, urgent countermeasures are needed to address the downslide of ichthyology in the country.

Acknowledgements

The authors wish to thank anonymous reviewers for their insightful comments that assisted to improve the manuscript.

References

Abell, R., Thieme, M.L., Revenga, C., Bryer, M., Kottelat, M., Bogutskaya, N., Coad, B., Mandrak, N. , Balderas, S.C., Bussing, W., Stiassny, M.L.J., Skelton, P., Allen, G.R., Unmack, P., Naseka, A., Ng, R., Sindorf, N., Robertson, J., Armijo, E., Higgins, J.V., Heibel, T.J. and Wikramanayake, E., Olson, D., Lopez, H.L., Reis, R.E., Lundberg, J.G., Perez, M.H.S. and Petry, P., 2008. Freshwater Ecoregions of the World: A New Map of Biogeographic Units for Freshwater Biodiversity Conservation. *BioScience*, 58(**5**), 403-414 .

Ahmad, A. and Khairul-Adha, A.R., 2005. State of Knowledge on Freshwater Fishes of Malaysia. Proceedings of the Seminar and Workshop. Forest Research Institute Malaysia, Kepong, Malaysia, 28-30 June 2005.

Atack, K., 2006. *The Fishes of Kuching Rivers, Sarawak, Malaysian Borneo*. Kota Kinabalu: Natural History Publication (Borneo).

Bird, M.I., Taylor, D. and Hunt, C., 2005. Palaeoenvironments of insular Southeast Asia duringthe Last Glacial Period: a savanna corridor in Sundaland? *Quaternary Science Reviews*, 24, 2228–2242.

Brosse, S., Beauchard, O., Blanchet, S., Dürr, H.H., Grenouillet, G., Hugueny, B., Lauzeral, C., Leprieur, F., Tedesco, P.A., Villeger, S. and Oberdorff, T., 2013. Fish-SPRICH: a database of freshwater fish species richness throughout the World. *Hydrobiologia*, 700(**1**), 343-349.

Cantor, T.E., 1849. Catalogue of Malayan fishes. *Journal of the Asiatic Society of Bengal*, 18, 981–1443.

Chen, W.J. and Mayden, R.L., 2009. Molecular Systematics of the Cyprinoidea (Teleostei: Cypriniformes), the World's Largest Clade of Freshwater Fishes: Further Evidence From Six Nuclear Genes. *Molecular Phylogenetics and* Evolution, 52, 544-549.

Chen, X., Yue, P. and Lin, R., 1984. Major groups within the family Cyprinidae and their phylogenetic relationships. *Acta Zootaxonomica Sinica*, 9, 424-440.

Chong, V.C., Lee, P.K.Y. and Lau, C.M., 2010. Diversity, extinction risk and conservation of Malaysian fishes. *Journal of Fish Biology*, 76, 2009–2066.

Collins, R.A., Armstrong, K.F., Meier, R., Yi, Y., Brown, S.D.J., Cruickshank, R.H., Keeling, S. and Johnston, C., 2012. Barcoding and border biosecurity: Identifying cyprinid fishes in the aquarium trade. *PLoS ONE*, 7, e28381.

Corner, E.J.H., 1960. The Malayan Flora. Proceedings of the Centenary and Bicentenary Congress of Biology, University Malaya, Singapore.

Danzmann, R.G. and Gharbi, K., 2001. Gene mapping in fishes: A means to an end. *Genetica*, 111, 3–23.

Department of Environment, Malaysia, 2014. Environmental Quality Report 2014. Available:

https://enviro.doe.gov.my/view.php?id=15791 [Accessed 12.10.2016].

Eadie, J.M., Hurly, T.A., Montgomerie, R.D. and Teather, K.L., 1986. *Enviromental Biology of Fishes*, 15, 2, 81-89.

Esa, Y.B., Siraj, S.S., Daud, S.K., Rahim, A. and Adha, K., 2006. Mitochondrial DNA Diversity of *Tor douronensis* Valenciennes (Cyprinidae) in Malaysian Borneo. *Pertanika Journal of Tropical Agricultural Science*, 29**,** 47-55.

Esa, Y.B, Siraj, S.S., Daud, S.K., Ryan, J.J.R., Rahim, K.A.A. and Tan, S.G., 2008. Molecular Systematics of Mahseers (Cyprinidae) in Malaysia Inferred from Sequencing of a Mitochondrial Cytochrome C Oxidase I (COI) Gene. *Pertanika Journal of Tropical Agriculture Science*, 31(**2**), 263-269.

Esa, Y.B, Siraj, S.S., Rahim, K.A.A., Daud, S.K., Ho, G.C., Tan, S.G. and Syukri, M.F., 2012. Genetic Characterization of Two Mahseer Species (*Tor douronensis* and *Tor tambroides*) Using Microsatellite Markers from Other Cyprinids. *Sains Malaysiana*, 40(**10**), 1087-1095.

Evans, K.L. and Gaston, K.J., 2005. Can the evolutionary-rates hypothesis explain species-energy relationships*?* *Functional Ecology*, 19, 899–915.

Froese, R. and Pauly, D. (eds.), 2016. FishBase, World Wide Web electronic publication, search by country. Available:http://www. fishbase.org/ Country/CountryChecklist. php? c_code= 458&vhabitat= fresh&csub_code= [Accessed 12.09.2016].

Hall, R., 2013. The palaeogeography of Sundaland and Wallacea since the Late Jurassic. *The Journal of Limnology*, 72, 1-17.

Haryono A.H.T., 2006. Morphological study for identification improvement of Tambra fish (Tor spp.: Cyprinidae) from Indonesia. Biodiversitas, **7**, 59-62.

Helfman, G.S., Collette, B.B., Facey, D.E. and Bowen, B.W., 2009. The diversity of fishes: biology, evolution and ecology. Oxford: Wiley-Blackwell Publishing.

Hugueny, B., Oberdorff, T. and Tedescco, P.A., 2010. Community Ecology of River Fishes: A Large-Scale Perspective. *American Fisheries Society Symposium*, 73.

Inger, R.F. and Chin, P.K., 1962. The freshwater fishes of North Borneo. *Fieldiana: Zoology*, 45, 1–268.

Inger, R.F. and Chin, P.K., 2002. The freshwater fishes of North Borneo, with a revised supplementary chapter. Kota Kinabalu: Natural History Publications (Borneo).

Ingram B., Sungan S., Tinggi D., Sim S.Y. and De Silva S.S., 2007. Breeding performance of Malaysian Mahseer, *Tor tambroides* and *T. douronensis* broodfish in captivity. *Aquaculture Research*, 38, 809-818.

Johnson, D.S., 1967. Distributional Patterns of Malayan Freshwater Fish. *Ecology*, 48(**5**), 722-730.

Jurasinski, G., Retzer, V. and Beierkuhnlein, C., 2009. Inventory, differentiation, and proportional diversity: a consistent terminology for quantifying species diversity. *Oecologia*, 159, 15–26.

Kamarudin, K.R. and Esa, Y., 2009. Phylogeny and phylogeography of Barbonymus schwanenfeldii (Cyprinidae) from Malaysia inferred using partial cytochrome b mtDNA gene. *Journal of Tropical Biology and Conservation*, 5, 1-13.

Kano Y., Adnan, M.S.B., Grudpan, C., Grudpan, J., Magtoon, W., Musikasinthorn, P., Natori, Y., Ottomanski, S., Praxaysonbath, B., Phongsa K., Rangsiruji, A., Shibukawa, K., Shimatani, Y., So, N., Suvarnaraksha, A., Thach, P., Thanh, P.N., Tran, D.D., Utsugi, K. and Yamashita, T., 2016. An online database on freshwater fish diversity and distribution in Mainland Southeast Asia. Available at: http://ffish.asia/?p=h [Accessed 23.09.2016].

Kapuscinski, A.R. and Miller, L.M., 2007. Genetic Guidelines For Fisheries Management. Available at: http://www.lssu.edu/faculty/gsteinhart/GBS-LSSU/BIOL372- Fish%20 Culture_files/Genetic_guidlines. pdf [Accessed 03.08.2016].

Khairul Adha A.R., 2011. The Contribution of Non-indigenous Fish for Aquaculture Development in Malaysia. *Majalah Akuakultur Malaysia MOA 2011*.

Khan, M.M.R, Sultana, N. and Rasul, M.N., 2013. Population Genetic Analysis of Striped Dwarf Catfish Golsha, Mystus cavasius (Hamilton 1822) Using Allozyme Markers in Bangladesh. *Asian Fisheries Science*, 26, 52-59.

Kottelat M. and Tan, H.H., 2011. *Systomus xouthos*, a new cyprinid fish from Borneo, and revalidation of *Puntius pulcher* (Teleostei: Cyprinidae). *Ichthyological* Exploration *of Freshwaters*, 22, 209-214.

Kottelat M., 2013. The Fishes of the Inland Waters of Southeast Asia: A Catalogue and Core Bibliography of the Fishes Known to Occur in Freshwaters, Mangroves and Estuaries. *The Raffles Bulletin of Zoology*, 27, 1-663.

Kottelat, M., 1999. Nomenclature of the genera Barbodsi, Cyclocheilichthys, Rasbora and Chonerhinos (Teleostei: Cyprininae and Tetraodontidae), with comments on the definition of the first reviser. *Raffles Bulletin of Zoology*, 47(**2**), 263-268.

Kottelat, M. and Whitten, T., 1996. Freshwater biodiversity in Asia, with special reference to fish. World Bank Technical Paper No. 343. Washington DC: World Bank.

Lee, P.K.Y., Ng, S.Y., Yong, D., Chai, X.C., Yin, W.F. and Chan, K. G., 2012. Molecular phylogeny characterization of Malaysian fighting fish *Betta pi* (Teleostei: Osphronemidae) based on its 18S ribosomal DNA sequences. *Asia Life Sciences*, 21(**1**), 1-8.

Leveque, C., Oberdorff, T., Paugy, D., Stiassny, M.L.J. and Tedesco, P.A.,

2008. Global diversity of fish (Pisces) in freshwater. *Hydrobiologia*, 595, 545–567.

Lim, K.K.P., Ng, P.K.L., Kottelat, M. and Zakaria-Ismail, M., 1993. A Preliminary Working List of Native Freshwater Fishes of Peninsular Malaysia. Malaysia: Asian Wetland Bureau & World Wide Fund for Nature Malaysia.

Lohman, D.J., Bruyn, M.D., Page, T., Rintelen, K.V., Hall, R., Ng, P.K.L., Shih, H.T., Carvalho, G.R. and Rintelen, T.V., 2011. Biogeography of the Indo-Australian Archipelago. *Annual Review of Ecology and Systematics*, 42, 205–226.

MacArthur, R.H., 1969. Patterns of communities in the tropics. *Biological Journal of the Linnean Society*, 1, 19–30.

Mengumphan, K. and Panase, P., 2015. Morphometric and meristic divergence of two hybrid catfish: backcross (F1 hybrid female × *Pangasianodon gigas* Chevey 1931 male) and reciprocal backcross (*P. gigas*, female × F1 hybrid male). *Asian Fisheries Science*, 28, 37-46.

Moghaddam, F.Y., Aliabadian, M., Daud, S.K. and Seifali, M., 2012. Molecular phylogeny of the *Puntius* (Hamilton, 1822) based on nuclear gene RAG2. *Progress in Biological Science*, 2(**2**), 66-75.

Nelson, J.S., 2006. Fishes of the World, 4th Edition. New Jersey: John Wiley & Sons Inc.

Nelson, G. and Paltnick, N., 1981. Systematics and Biogeography: Cladistics and Vicariance. New York: Colombian University Press.

Ng, H.H. and Tan, H.H., 1999. The fishes of the Endau drainage, Peninsular Malaysia with descriptions of two new species of catfishes (Teleostei: Akysidae, Bagridae). *Zoological Studies*, 38(**3**), 350-366.

Ng, H.H. and Lim, K.K.P., 2005. The identity of *Pseudomystus moeschii* (Boulenger, 1890), with the description of two new species of bagrid catfishes from Southeast Asia (Teleostei: Bagridae). *Zootaxa*, 851, 1–18.

Ng, H.H., 2010. A new species of miniature catfish from the Malay Peninsula (Teleostei: Bagridae: *Nanobagrus*). *Zootaxa*, 2677, 60–68.

Nguyen, T.T.T., 2008. Population structure in the highly fragmented range of *Tor douronensis* (Cyprinidae) in Sarawak, Malaysia revealed by microsatellite DNA markers. *Freshwater Biology*, 53, 924-934.

Pethiyagoda, R., Madhava, M. and Kalana, M., 2012. A synopsis of the South Asian fishes referred to *Puntius* (Pisces: Cyprinidae) *Ichthyological Exploration of Freshwaters*, 23, 69-95.

Rahim, K.A.A., Esa, Y. and Arshad, A., 2013. The Influence of Alien Fish Species on Native Fish Community Structure in Malaysian Waters. *Kuroshio Science*, 7(**1**), 81-93.

Rainboth, W.J., 1991. Cyprinid fishes of Southeast Asia. London: Chapman and Hall.

Rajasekaran, N. and Sivakumar, R., 2016. Variations of vertebral bones among freshwater *Puntius* (Teleostei: Cyprinidae) from Lower Anicut, Tamil Nadu. *Asian Journal of Multidisciplinary Studies*, 4(**2**), 55-63.

Ricklefs, R.E., 2004. A comprehensive framework for global patterns in biodiversity. *Ecology Letters*, 7, 1–15.

Roberts, T.R., 1989. The freshwater fishes of Western Borneo (Kalimantan Barat, Indonesia). *Proceedings of the California Academy of Sciences*, 14, 1–210.

Roberts, T.R., 1993. Systematic Revision Of The Southeast Asian Cyprinid Fish Genus *Labiobarbus* (Teleostei: Cyprinidae). *Raffles Bulleting of Zoology*, 41(**2**), 315-329.

Rosenzweig, M.L., 1995. Species diversity in space and time. Cambridge: Cambridge University Press.

Shantakumar, M. and Vishwanath, W., 2006. Inter-relationship of *Puntius* Hamilton-Buchanan (Cyprinidae: Cyprininae) found in Manipur, India. *Zoo's Print Journal*, 21(**6**), 2279-2283.

Tan, H.H., 2006. The Borneo Suckers: Revision of the Torrent Loaches of Borneo (Balitoridae: Gastromyzon, Neogastromyzon). Kota Kinabalu: Natural History Publication (Borneo).

Tan, M.P., Jamsari, A.F.J and Siti Azizah, M.N., 2012. Phylogeographic Pattern of the Striped Snakehead, *Channa striata*, in Sundaland: Ancient River Connectivity, Geographical and Anthropogenic Signatures. *PLoS ONE*, 7(**12**).

Vipin, P.M., Pradeep, K., Ravi, Fernandez, R.J., Ramesan, M.P., Madhu, V.R. and Boopendranath, M.R., 2011. First Estimate of the Length–Weight Relationship of *Diaphus watasei* Jordan and Starks, 1904 Caught off the Southwest Coast of India. *Asian Fisheries Science*, 24, 453-455.

Voris, H.K., 2000. Maps of Pleistocene sea levels in Southeast Asia: Shorelines, river systems and time durations. *Journal of Biogeography*, 27, 1153-1167.

Wiley, E.O., 1988. Vicariance Biogeography. *Annual Review of Ecology and Systematics*, 19, 513-542.

Wong, C.L., Venneker, R., Uhlenbrook, S., Jami, A.B.M. and Zhou, Y., 2009. Variability of rainfall in Peninsular Malaysia. *Hydrology and Earth System Sciences Discussions*, 6, 5471–5503.

Wright, S., Gray, R.D. and Gardner, R.C., 2003. Energy and the rate of evolution: inferences from plant rDNA substitution rates in the western Pacific. *Evolution*, 57, 2893–2898.

Zakaria-Ismail, M., 1992. Background paper on marine and freshwater fishes. Malaysia: Prime Minister Department Malaysia.

Zakaria-Ismail, M., 1994. Zoogeography and biodiversity of the freshwater fishes of Southeast Asia. *Hydrobiologia*, 285(**1-3**), 41-48.