Biol Invasions
https://doi.org/10.1007/s10530-024-03399-y

INVASION NOTE

Using citizen science data to uncover the invasion of the non-native fish, *Hemibagrus wyckioides* (Fang and Chaux, 1949) in Peninsular Malaysia

Mohamad Aqmal-Naser · Intan-Faraha A. Ghani · Muhammad Rasul Abdullah Halim · Muhammad Fahmi-Ahmad · Md. Zain Khaironizam · Mohammad Noor Azmai Amal · Zahar Azuar Zakaria · Mohd Lokman Ilham-Norhakim · Amirrudin B. Ahmad

Received: 8 February 2024 / Accepted: 10 July 2024

Abstract Knowledge on the distribution of non-native fishes is critical to assess the current status of biological invasions and prevent further spread and impacts. This study aims to synthesize current distributional data of the non-native catfish, *Hemibagrus wyckioides*, an emerging invader in Peninsular Malaysia. We collected occurrence data from Facebook groups created by anglers and freshwater fish enthusiasts, which were used to map the distribution of the species. A total of 106 occurrences of *H. wyckioides* were recorded in five states, with three major invasion hotspots identified—Selangor, Pahang and Perak. Given the scarcity of distributional data for this species within the published literature, social media platforms provided invaluable information on the current distribution of this emerging invader, highlighting their potential utility in early detection and monitoring of poorly-known non-native fishes.

Abstracto El conocimiento sobre la distribución de peces no nativos es fundamental para evaluar el estado actual de las invasiones biológicas y prevenir una mayor propagación e impactos. Este estudio tiene como objetivo sintetizar los datos de distribución actuales del bagre no nativo, *Hemibagrus wyckioides*, un

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10530-024-03399-y.

M. Aqmal-Naser · A. B. Ahmad (✉)
Terrestrial Biodiversity, Ecology and Aquatic Research (TEBAR), Institute of Tropical Biodiversity and Sustainable Development, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia
e-mail: amirrudin@umt.edu.my

I.-F. A. Ghani
Faculty of Engineering and Life Sciences, University Selangor, 45600 Bestari Jaya Selangor, Malaysia

M. R. A. Halim
Faculty of Science, Universiti Malaya Institute of Biological Sciences, 50603 Kuala Lumpur, Malaysia

M. Fahmi-Ahmad · A. B. Ahmad
Biodiversity and Ecological Research (BERes), Faculty of Science and Marine Environment, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia

Md. Zain. Khaironizam
School of Biological Sciences, Universiti Sains Malaysia, 11800 Penang, Malaysia

M. N. A. Amal
Department of Biology, Faculty of Science, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

Z. A. Zakaria
Hospital Kemaman, Jalan Da' Omar, Chukai, 24000 Kemaman, Terengganu, Malaysia

M. L. Ilham-Norhakim
Environmental Management and Conservation Research Unit (eNCORe), Faculty of Applied Science and Technology, Universiti Tun Hussein Onn Malaysia (Pagoh Campus), 84600 Pagoh, Johor, Malaysia

Published online: 12 August 2024

invasor emergente en Malasia Peninsular. Recopilamos datos de ocurrencia de grupos de Facebook creados por pescadores y entusiastas de los peces de agua dulce, que se utilizaron para mapear la distribución de la especie. Se registraron un total de 106 apariciones de *H. wyckioides* en cinco estados, con tres importantes puntos críticos de invasión identificados: Selangor, Pahang y Perak. Dada la escasez de datos sobre la distribución de esta especie en la literatura publicada, las plataformas de redes sociales proporcionaron información invaluable sobre la distribución actual de este invasor emergente, destacando su utilidad potencial en la detección temprana y el seguimiento de peces no nativos poco conocidos.

Keywords Asian redtail catfish · Invasive species · Monitoring · Protected area · River basins

Introduction

Fishes from the order Siluriformes (catfish) are among the most highly desirable fish for aquaculture worldwide (Kumar et al. 2020). The red-tail catfish (*Hemibagrus wyckioides*) which belongs to the order Siluriformes and family Bagridae, is the largest species from the family, reaching 130.0 cm total length and 80.0 kg weight (Ng and Rainboth 1999). Generally, it can easily be distinguished from other bagrid catfish by its bright red caudal fin. The species is favoured for its high protein content and better production performance, ease of domestication, and strong disease resistance (Zhou et al. 2021). The male fish exhibit faster growth rate compared to female and it takes three years to reach their sexual maturation (Shao et al. 2021). This species, a well-known predator, consumes a wide variety of aquatic fauna, including crabs, shrimps and fishes (Ng and Kottelat 2013). It has a wide native distribution range from the Mekong basin in Yunnan Province of China, Vietnam, Laos, and Cambodia to the Chao Phraya and Mae Klong drainages in Thailand (Panitvong 2020). The fish performed localised migration where it moves into moves into the flooded forest during the periods of high-water levels (Ng and Rainboth 1999) to breed. There is no documented invasion of this catfish outside its native distribution range. Its preferred habitat typically consists of large upland rivers, with sandy and rocky bottoms and irregular depths (Vidthayanon 2012). The presence of *Hemibagrus wyckioides* has been notably reported in Peninsular Malaysia, particularly in Pahang River, in the state of Pahang (Samah 2022). The exact time period of the introduction is uncertain but the trend show that the species is an emerging invader. Furthermore, its distribution in the other river basins of Peninsular Malaysia is currently unknown due to the scarcity of research and data collection, partially owing to insufficient funding and the lack of freshwater invasion specialists within the country. Consequently, citizen science and social media platforms (e.g., Facebook, TikTok) may provide alternative avenues from which distributional data may be collected from, given that hobbyist fish collectors and anglers frequently post their catches and share their experiences on these social media platforms. In recent years, this has substantially expanded the available information pool on the distribution of non-native species (Roy et al. 2015; Crall et al. 2020), and has facilitated the monitoring of biological invasions over large temporal and spatial scales (Giovos et al. 2019; Martelo et al. 2021). To better understand the current distribution of this non-native catfish occurrence in Peninsular Malaysia, this study aims to achieve the following objectives: 1) Determine the spatial distribution of *Hemibagrus wyckioides* in Peninsular Malaysia using social media through citizen science data, and 2) Assess the potential use of the data recorded to manage the spread of *Hemibagrus wyckioides* in the wild

Material and methods

Extensive data mining for *Hemibagrus wyckioides* records were performed using different sources of information: 1) from scientific publications (peer-reviewed journals) and 2) citizen science (anglers and fish enthusiastic) data from Facebook. For citizen science data, we use the data from five Facebook groups which were created by freshwater fish enthusiasts and anglers in Peninsular Malaysia. We opted for Facebook as it facilitated more efficient data collection owing to users being able to create groups where they can share photos and converse in the comment sections, compared to Tiktok or Instagram platforms which are less focused on community interaction. The local Facebook groups included ‘‘Ikan Air Tawar Malaysia’’ (28,600 members), “Kelab Memancing

Baung Malaysia" (13,900 members), ''Kaki Pancing Malaysia" (632,000 followers), "Kelab Joran Facebook" (321,900 members), and "Geng Pancing Malaysia" (190,000 members). The following keywords were used for our Facebook searches—"Baung Ekor Merah", "Red Tail Catfish" and "*Hemibagrus wyckioides*". The Facebook records were only included in our study if they included pictures or videos which allowed us to confidently validate species identities (Gago et al. 2016). We then used QGIS software to map the distribution of *H. wyckioides* within the river basins and states of Peninsular Malaysia. Unfortunately, we were unable to obtain precise GPS coordinate information for many records, and in most cases, only the general location (i.e., name of the river or district/area) was provided. Requests to the original posters for precise locations were often unsuccessful. To overcome this limitation, we use the HydroBASINS Level 10 sub-basin to delineates the river drainages within the area or district where the species occur. We also calculated occurrence densities per state within Peninsular Malaysia to identify invasion hotspots.

Results

Our literature review indicated that there have yet to be any scientific publications focused on the distribution of *H. wyckioides* in Peninsular Malaysia. Based on the Facebook data from 2013 until August 2023, the state of Selangor recorded the highest occurrence of *H. wyckioides* (34 occurrences), followed by Pahang (23 occurrences), Perak (21 occurrences), Johor (three occurrences) and Terengganu (one occurrence) while there are 24 unspecified locations on the occurrence of this catfish (Fig. 1). The state of Selangor has reported the occurrence of this species in six rivers namely Selangor, Semenyih, Langat, Bernam, Jenderam and Rawang Rivers, followed by the state of Perak (Perak, Kinta, and Kampar Rivers), the state of Pahang (Pahang and Jelai Rivers), the state of Johor (Johor, Muar and Telor Rivers), and the state of Terengganu (Telemung River) (Table S1). Based on the spatial map produced, we have identified three major river basins in Peninsular Malaysia which recorded higher occurrences of *H. wyckioides* which are the Selangor River basins, Perak River basins, and Pahang River basins (Fig. 2), suggesting that these are invasion hotspots. The temporal pattern on the occurrence of *H. wyckioides* from Facebook data shows that the earliest record was on 2013 in Pahang. Meanwhile, no record from Selangor state in

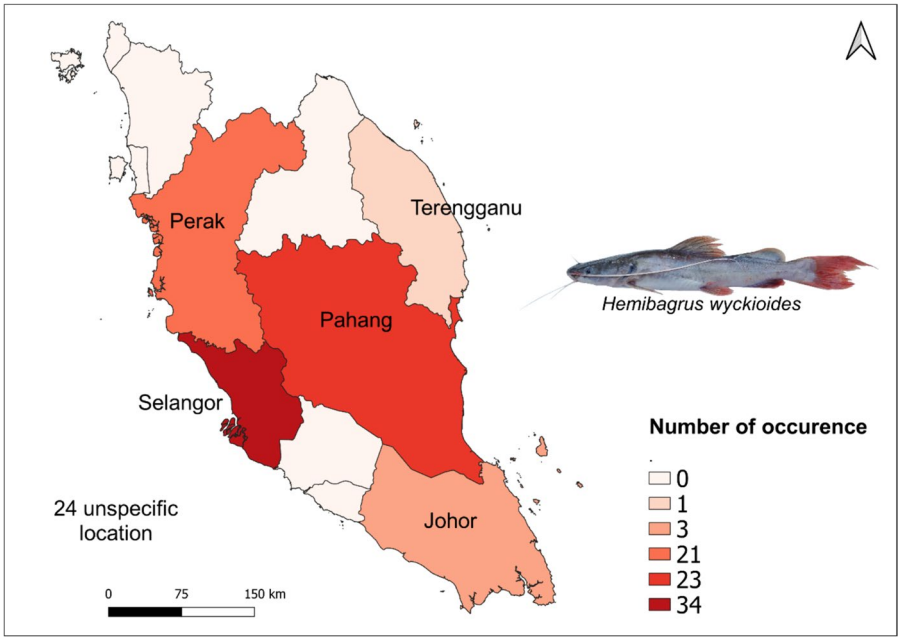

Fig.1 Occurrence densities of *Hemibagrus wyckioides* per state in Peninsular Malaysia

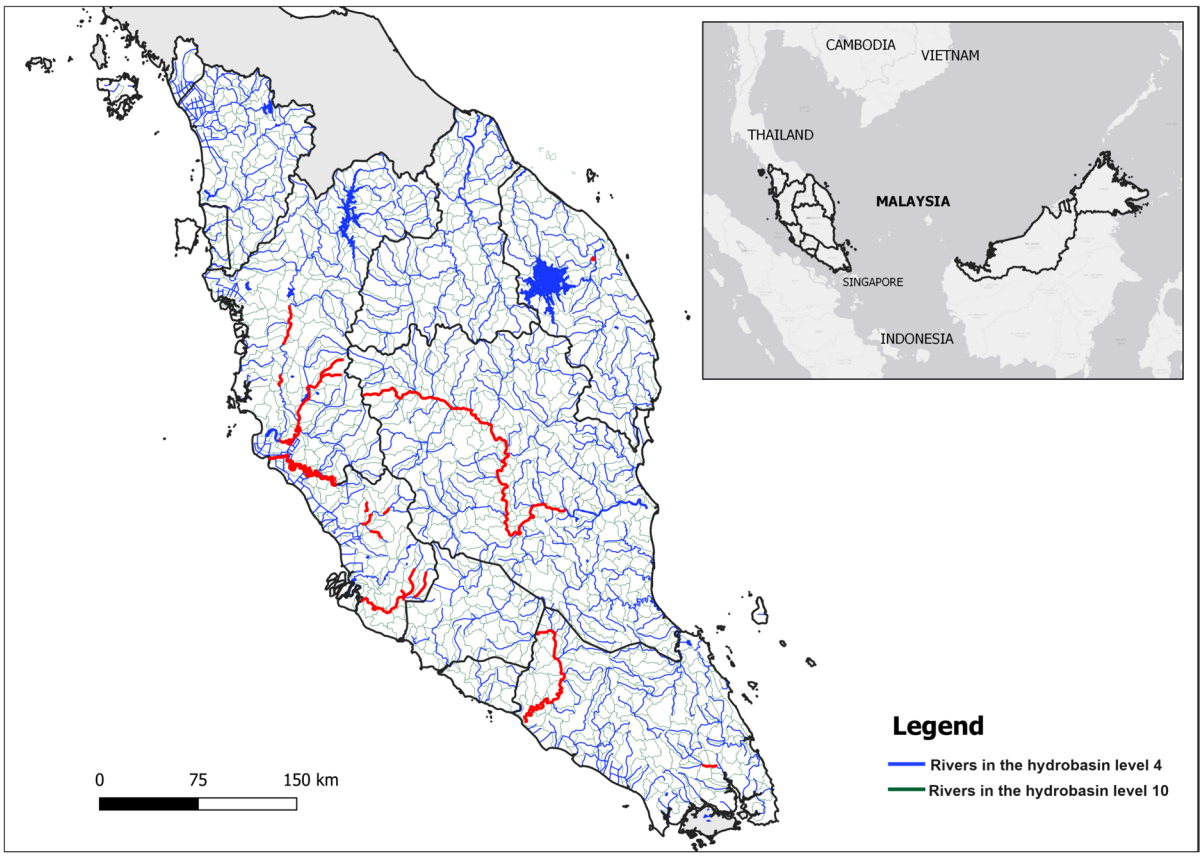

Fig.2 The occurrence of *Hemibagrus wyckioides* in the hydrobasin within the state in Peninsular Malaysia is shown by red line colour

2018 and 2019 meanwhile the record from Johor state appears to start in 2020 (Figure S1).

Discussion

The present study highlights the utility of online data from social media platforms (e.g., Facebook) to determine the spatial distribution of non-native fishes, especially in areas where there is a scarcity of information in the published literature. The data is immediately accessible and free, thereby providing an economical alternative or complementary source of information to field surveys that can be costly and labour intensive. Nonetheless, social media data has its limitations; for example, the time of arrival of this species into the river basins of Peninsular Malaysia is relatively unknown and the pathway of introduction is also ambiguous. The earliest online record data of *H. wyckioides* dates back to 2013 at Pahang River from Facebook data, but its arrival in Peninsular Malaysia could be earlier but unreported due to the limited utilization of social media before 2013.

In aquaculture, *H. wyckioides* does not exhibit cannibalism, making it an excellent predatory fish to farm (Jiwyam and Nithikulworawong 2014). Furthermore, the species can tolerate hypoxia and has substantial adaptability (Ng and Rainboth 1999). Our recent study visit to Pahang state shows that the price of the fish can be as high as USD 9.44 (RM45.00) per kilogram compared to *Hemibagrus capitulum*; native fish with USD 7.34 (RM35) per kilogram (Fig. 3). This species is more desirable as it possess faster growth rate (Zhang et al. 2020), which can reach up to 10.23% per day or 0.85 to 3.25 cm in 6 weeks (Amornsakun 2000). Plus, some people claim that the species is more delicious compared to the native catfish, and sold about USD 4.25 (RM20.00) per piece

Fig.3 Native *Hemibagrus capitulum* (yellow arrow) and non-native fish *Hemibagrus wyckioides* (red arrow) sold in the Temerloh wet market of Pahang, Peninsular Malaysia

in the local food stall especially in Pahang (personal observation). This species has been said to feed on various aquatic animals especially fish and prawn, hence the invasive characteristics of this species outside their native range need further study and monitoring for documentation and proofs. As the species shares many characteristics with another invasive species in Asia, in particular the African sharptooth catfish *Clarias gariepinus*, the potential impact similar to what has been observed by the introduction of this African catfish is expected. The inter-basin transfer is anticipated as this catfish is a localised migratory species. This species will also probably displace other native catfish such as *Hemibagrus capitulum* and *H. wyckii* given that congeners might be expected to overlap substantially in their niches and therefore compete for shared resources in the natural ecosystem. A recent study by Low et al. (2022) found that *Clarias gariepinus* have negative impact on the native *Clarias batrachus* where the species is either being displaced or extirpated in some area. This extirpation is contributed by both habitat and trophic competition. Since the species is carnivorous, they can feed on various aquatic fauna (Ng and Kottelat 2013), which later on can reduce the population of several important native crustacean such as giant freshwater prawns, *Macrobrachium rosernbergii* and native fish species in the rivers. Pahang is known as one of the largest sources for freshwater fish landing in Peninsular Malaysia, could be affected by the establishment of this catfish.

The escape from the cage culture after catastrophic events such as massive flooding is one of the examples of how this species may have been introduced into the wild. The recent flooding in the Perak River in 2022 destroyed many aquaculture cages, facilitating the further spread of this species (Bernama 2022). Even though *H. wyckioides* is not listed as a prohibited species for importation into Malaysia in The Malaysian Fisheries Act 1985, this species has already been categorised as non-native fish species requiring proper documentation (including permits by the Department of Fisheries) before being imported and cultured. The failure of individuals or companies to comply with these rules constitutes illegal smuggling into Peninsular Malaysia.

Apart from escapes from aquaculture facilities, we postulate several other possibilities of how this species may have been introduced to the river basins of Peninsular Malaysia. Stocking of fish fry is one of the common methods proposed to boost depleted fishery stocks (Bell et al. 2008). In the case of Peninsular Malaysia, the restocking of fishes, especially *Hemibagrus* catfishes, is common. Nonetheless, there is often uncertainly regarding which species are being used for restocking projects, given that the fry of *H. wyckioides* are morphologically similar to those of other *Hemibagrus* species, and can only be differentiated upon reaching a length of 15 cm (when the red coloration on the caudal fin starts appearing) (Ng and Rainboth 1999). It is therefore possible that the species may have been inadvertently introduced through restocking programmes, given its status as a popular aquaculture species. Mercy releases by religious devotees also can be another possibility enhancing the spread of *H. wyckioides* in Peninsular Malaysia. Mercy release is one of the major pathways of non-native fish species introductions (Everard et al. 2019). In Peninsular Malaysia, mercy release of non-native fish species has been reported, mainly using African catfish, *Clarias gariepinus* (Aziz 2017). Nonetheless, *Hemibagrus* species are also occasionally chosen for mercy releases, which may include both *H. wyckioides* as well as native counterparts owing to difficulties in differentiating them morphologically. We expect this species to become a strong competitor with the other catfish such as *Bagarius lica, Hemibagrus capitulum* and *Hemibagrus wyckii* due to the same overlapping niche and food preferences. This species can also be found in the recreational fishing industry, especially in private fishing ponds (Amang 2019), where its fighting prowess and large size

makes it highly attractive to anglers. Consequently, escapes from these facilities, especially during major floods, may contribute to the spread of this species in natural waterbodies. On the other hand, it is probably less likely that the aquarium trade is a significant invasion pathway for the species in Peninsular Malaysia as it is seldom seen in the local aquarium trade, possibly due to its enormous adult size (Jiwyam and Nithikulworawong 2014). Nonetheless, previous studies (e.g., Aqmal-Naser and Ahmad 2020) have shown that large aquarium species may be subjected to higher frequencies of intentional releases (i.e., dumping), since they can quickly outgrow their enclosures and are harder to maintain long-term. The study of the ecology of this species, particularly in Peninsular Malaysia is indispensable. The information on the changes in their spatial and temporal distribution is important to determine the invasion stage. For example, Terengganu and Johor states show initial stage of invasion, but the invasion in Terengganu is possibly unsuccessful as only once occurrence recorded in 2015. The occurrence of the species in the Johor state now can be monitored and the species must be eradicated immediately. Our data suggests that the invasions in the states of Perak, Pahang and Selangor appear to be relatively advanced, given that the species has been consistently recorded from these three states in most years since 2014. In the Pahang state, there was an increase in the landing of *H. wyckioides* where, in 2021 about 23.348 metric tonnes of this catfish were landed and 38.241 metric tonnes in 2022, an increase of 15.893 metric tonnes (Basha 2022) which signal an established population of *Hemibagrus wyckioides*. At the moment, the realistic and possible methods to contain the spreading of this species are by meticulously screening the fry provided or bought especially for restocking within Peninsular Malaysia. The removal of juvenile and adult of the species must be done through the cooperation between the state government and the state department of fisheries as what has been done in several localities in Pahang (Malek 2022) and Perak (Bernama 2022). Apart from that, the existence of highly passionate and dedicated teams of anglers known as River Monster Hunter (https://www.facebook.com/rivermonsterchannel), which focuses on eradicating *H. wyckioides* deserves appreciation and recognition. Our occurrence dataset might be a little bit biased as anglers often exhibit preferences for particular fishing locations (Marta et al. 2001). Nonetheless, our social media data offers crucial, albeit preliminary, insights into which areas are existing and potentially emerging invasion hotspots, which can inform management strategies and resource prioritisation.Finally, we anticipate that our study can further motivate citizen scientists to share information and contribute towards invasive species research in Peninsular Malaysia. Crucial information such as length, weight, precise GPS location, and proper photographs for documentation are examples of additional data that can be provided by citizen scientists. To better aid monitoring programs, social media platforms such as Facebook can be used to create formal citizen-science groups devoted to the sharing and long-term archiving of information on non-native species.

Acknowledgements M.A-N and ABA would like to thank Universiti Malaysia Terengganu and Institute of Tropical Biodiversity and Sustainable Development for the support and facilities to conduct this study. All authors are grateful to the members of the Facebook groups and fish enthusiastic for their information and knowledge sharing. We also thank the Associate Editor in handling the submission of the manuscript and two reviewers for a very supportive comments and suggestions on the earlier version and significantly improving the content of this paper.

Author contributions All authors contributed to the study conception and design. All authors involved in the data collection. Material preparation and analysis were performed by Mohamad Aqmal-Naser. The first draft of the manuscript was written by Mohamad Aqmal-Naser and Amirrudin B. Ahmad. All authors commented and make amendments on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding The authors have not disclosed any funding.

Declarations

Conflict of interests All authors have no competing interest to disclose.

References

Amang (2019) Umpan. Umpan Baung Ekor Merah Kolam!!. https://www.umpan.com.my/umpan-baung-ekor-merah-kolam/. Accessed on 31 August 2023

Amornsakun T (2000) Influences of initial delay of feeding on growth and survival of larval red-tail catfish mystus wyckioides. Warasan Songkhlanakarin 51–55

Aqmal-Naser M, Ahmad AB (2020) First report of the hybrid blood parrot cichlid from a rice agroecosystem in seberang perai tengah, penang, peninsular malaysia, with

notes on syntopic midas cichlid, *Amphilophus citrinellus* (Günther, 1864). BioInvasions Rec 9(3):588–598. https://doi.org/10.3391/bir.2020.9.3.15

Aziz IH (2017). Berita Harian Online. Keli Afrika ancaman ekosistem sungai tempatan. https://www.bharian.com.my/node/258857. Accessed on 13 August 2022

Basha AN (2022) Sidang Dewan Negeri: Pendaratan Ikan Pemangsa Baung Ekor Merah Meningkat 15 Tan Metrik Di Pahang. https://www.pahang.gov.my/pahang/resources/PDF/Berita/2022/Oktober%202022/(13hb)_Sidang_Dewan_Negeri,_Pendaratan_Ikan_Pemangsa_Baung_Ekor_Merah_Meningkat_15_Tan_Metrik_Di_Pahang.pdf. Accessed on 20 September 2022

Bell JD, Leber KM, Blankenship HL, Loneragan NR, Masuda R (2008) A new era for restocking, stock enhancement and sea ranching of coastal fisheries resources. Reviews Fish Sci 16(1–3):1–9. https://doi.org/10.1080/10641260701776951

Bernama (2022) Exco minta nelayan mendaratkan ikan baung ekor merah https://www.malaysiakini.com/news/647439. Accessed on 12 September 2022.

Crall AW, Mellor D, Gray S, Newman G (2020) Collecting High-Quality Data. In: Lepczyk CA, Boyle OD, Vargo TLV (eds) Handbook of Citizen Science in Ecology and Conservation. University of California Press California, pp 119–136

Everard M, Pinder AC, Raghavan R, Kataria G (2019) Are well-intended Buddhist practices an under-appreciated threat to global aquatic biodiversity? Aquat Conserv: Mar Freshw Ecosyst 29(1):136–141

Gago J, Anastácio P, Gkenas C, Banha F, Ribeiro F (2016) Spatial distribution patterns of the non-native European catfish, *Silurus glanis*, from multiple online sources - a case study for the River Tagus (Iberian Peninsula). Fish Managa Ecol 23:503–509. https://doi.org/10.1111/fme.12189

Giovos I, Kleitou P, Poursanidis D, Batjakas I, Bernardi G, Crocetta F, Doumpas N, Kalogirou S, Kampouris TE, Keramidas I, Langeneck J, Maximiadi M, Mitsou E, Stoilas VO, Tiralongo F, Romanidis-Kyriakidis G, Xentidis NJ, Zenetos A, Katsanevakis S (2019) Citizen-science for monitoring marine invasions and stimulating public engagement: a case project from the eastern Mediterranean. Biol Invasions 21:3707–3721. https://doi.org/10.1007/s10530-019-02083-w

Jiwyam W, Nithikulworawong N (2014) Stocking density-dependent growth and survival of Asian red-tailed catfish (*Hemibagrus wyckioides*) fries: early nursing in cages. Int Aquat Res 6:245–250. https://doi.org/10.1007/s40071-014-0084-4

Kumar G, Engle C, Hegde S, Senten J (2020) Economics of U.S. catfish farming practices: profitability, economies of size, and liquidity. J World Aquaculture Soc 51:829–846. https://doi.org/10.1111/jwas.12717

Low BW, Liew JH, Tan HH, Ahmad A, Zeng Y, Yeo DC (2022) The invasion and impacts of the African sharptooth catfish (Clariidae: Clarias gariepinus) in the malay peninsula. Freshw Biol 67(11):1925–1937

Malek RA (2022) Baung ekor merah ancam pendapatan nelayan. https://www.hmetro.com.my/mutakhir/2022/09/878825/baung-ekor-merah-ancam-pendapatan-nelayan-metrotv. Accessed on 17 September 2023

Marta P, Bochechas J, Collares-Pereira MJ (2001) Importance of recreational fisheries in the guadiana river basin in portugal. Fish Manag Ecol 8(4–5):345–354. https://doi.org/10.1111/j.1365-2400.2001.00262.x

Martelo J, Costa L, Ribeiro D, Gama M, Banha F, Anastácio P (2021) Evaluating the range expansion of recreational non-native fishes in Portuguese freshwaters using scientific and citizen science data. Bioinvasions Rec 10:378–389. https://doi.org/10.3391/bir.2021.10.2.16

Ng HH, Kottelat M (2013) Revision of the asian catfish genus *Hemibagrus* Bleeker, 1862 (Teleostei: Siluriformes: Bagridae). Raffles Bull Zool 61(1):205–291

Ng HH, Rainboth WJ (1999) The bagrid catfish genus *Hemibagrus* (Teleostei: Siluriformes) in central Indochina with a new species from the mekong River. Raffles Bull Zool 47:553–574

Panitvong N (2020) A photographic guide to freshwater fishes of Thailand. Siamensis Press, p 768

Roy HE, Rorke SL, Beckmann B, Booy O, Botham MS, Brown PM et al (2015) The contribution of volunteer recorders to our understanding of biological invasions. Biol J Linn Soc 115:678–689. https://doi.org/10.1111/bij.12518

Samah NN (2022) Ikan baung ekor merah jadi ancaman di Jerantut. https://bebasnews.my/2022/12/27/ikan-baung-ekor-merah-jadi-ancaman-di-jerantut/. Accessed on 09 September 2023.

Shao F, Pan H, Li P, Ni L, Xu Y, Peng Z (2021) Chromosome-level genome assembly of the asian red-tail catfish (*Hemibagrus wyckioides*). Front Genet 12:747684. https://doi.org/10.3389/fgene.2021.747684

Vidthayanon C (2012) *Hemibagrus wyckioides*. The IUCN Red List of Threatened Species 2012: e.T180905A1676163. https://doi.org/10.2305/IUCN.UK.2012-1.RLTS.T180905A1676163.en. Accessed on 25 September 2023.

Zhang X, Wang H, Zhang J, Lin B, Chen L, Wang Q, Li G, Deng J (2020) Assessment of rapeseed meal as fish meal alternative in diets for juvenile asian red-tailed catfish (*Hemibagrus wyckioides*). Aquac Rep 18:100497. https://doi.org/10.1016/j.aqrep.2020.100497

Zhou Y-L, Wang Z-W, Guo XF, Wu J-J, Lu W-J, Zhou L et al (2021) Construction of a high-density genetic linkage map and fine mapping of qtls for growth and sex-related traits in red-tail catfish (*Hemibagrus wyckioides*). Aquaculture 531:735892. https://doi.org/10.1016/j.aquaculture.2020.735892