© Asian Fisheries Society
Published under a Creative Commons license
E-ISSN: 2073-3720
https://doi.org/10.33997/j.afs.2023.36.3.002

A Review of Suckermouth Armoured Catfish (Siluriformes: Loricariidae) Invasion, Impacts and Management: Is Its Invasion a Threat to Bangladesh's Fisheries Sector?

ANTAR SARKAR[1], SAIFUDDIN RANA[1], PRANTA BHOWMIK[1], MD. NAZMUL HASAN[2], SHAHIDA ARFINE SHIMUL[1], SK. AHMAD AL NAHID[1,*]
[1]Department of Fisheries Resource Management, Faculty of Fisheries, Chattogram Veterinary and Animal Sciences University, Chattogram, Bangladesh
[2]Department of Oceanography, University of Chittagong, Chattogram, Bangladesh

*E-mail: nahid83bau@gmail.com | Received: 05/03/2023 Accepted: 07/09/2023

Abstract

Suckermouth armoured catfish of the genus *Pterygoplichthys* (Siluriformes: Loricariidae) are significant threats to aquatic biodiversity, ecosystems, habitats, and fishery production in different countries. Their unique characteristics and adaptive features help their successful invasion. These fish harm fish habitats, compete for food and space, prey on fish eggs, and displace the native fish populations. They erode river banks, alter benthic ecology, make holes in the river bank, and remove aquatic plants. Elimination, control, and intrusion prevention are possible management strategies. Utilising them as food and preparing value-added products and byproducts using them are viable ways to reduce their number. Management is challenging, owing to their tolerance and excellent adaptability. With severe dangers to Bangladesh's fisheries industry and aquatic environment, suckermouth armoured catfish have invaded natural waterbodies and aquaculture ponds. There is a lack of accurate information on invasion status, types of invading species, and potential dangers of invasion to create a management framework in Bangladesh. Therefore, this review introduces the key characteristics, habitats, invasion impacts, and management and utilisation aspects of suckermouth armoured catfish in different countries. The review may help in understanding how they affect native fish, aquatic organisms, habitats, and the aquatic environment globally. Finally, what kind of threats they may pose and how they can be managed sustainably in Bangladesh.

Keywords: aquatic biodiversity, ecosystem, habitat, invasion control, effects

Introduction

Suckermouth armoured catfish (SMCF) of the genus *Pterygoplichthys* (Siluriformes: Loricariidae) are the most speciose family in the order Siluriformes. They are common aquarium pets because of their distinctive appearance and algae-cleaning nature (Wu et al., 2011). Members of the genus *Pterygoplichthys* have become invasive in many countries (Chaichana and Jongphadungkiet, 2012). They have reached five continents and twenty-one countries (Orfinger and Goodding, 2018). They can expand their population within 5-10 years of introduction into a waterbody (Mendoza-Alfaro et al., 2009). SMCF invasion affects ecosystem function, biodiversity, national economies, and public health (Mack et al., 2000). They threaten the native fish population in introduced waterbodies (Nico et al., 2009; Capps and Flecker, 2013; Rubio et al., 2016).

SMCF invades natural waterbodies through three known pathways: escape from aquaculture facilities, release from aquariums, and exposure from biocontrol setups (Hoover et al., 2014). However, intentional release from aquariums is considered the primary cause of invasion (Mendoza-Alfaro et al., 2010). Several characteristics of SMCF lead to invasion success (Marchetti et al., 2004). Their unique feeding habits, reproductive behaviour, and population establishment help threaten native fish in introduced waterbodies (Hoover, 2004). They compete with similar-sized aquatic organisms for food and space and may disturb other animals in the same habitat (Englund, 2000). They erode banks, alter benthic habitats (Hoover et al., 2014), create deep burrows on the river bank and bottom (Burgess, 1989), and displace other aquatic animals (Flecker, 1992).

Management strategies for invasion include eradication (Hoover, 2004), control, and prevention of intrusion (Hussan et al., 2021; Qasim and Jawad, 2022; Wei et al., 2022). However, their great tolerance and adaptability (Nico and Martin, 2001; MacCormack et al., 2003; Hoover et al., 2014) may create difficulties in management. They have some utilisation as food, fish and animal feed ingredients, value-added products, and byproducts (Hoover, 2004; Ariyarathne et al., 2016; Herath et al., 2020; Puspitasari et al., 2021) with safety issue consideration (Elfidasari et al., 2018).

Bangladesh is one of the most significant fish-producing countries in the world, with abundant freshwater and marine fishery resources. It holds the third position in inland open-water fish capture and fifth position in world aquaculture production (DoF, 2020). SMCF were imported to Bangladesh for the ornamental pet trade but were gradually introduced into aquaculture ponds, natural waterbodies, and critical aquatic habitats (Hossain et al., 2008; Newagebd, 2020; Newagebd, 2021) (Fig. 1). There is a lack of organised information in Bangladesh on the status of SMCF invasion, types of species invaded, and possible threats and impacts on aquatic ecosystems and biota.

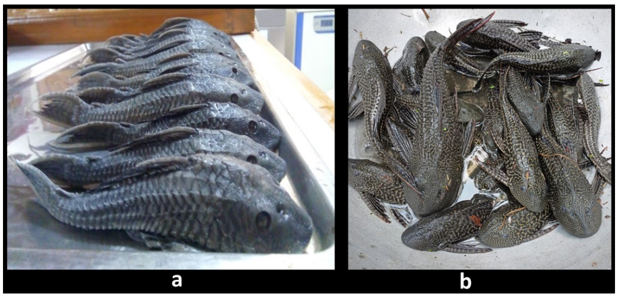

Fig. 1. *Pterygoplichthys* spp. collected from the a) Buriganga River, Dhaka, and b) aquaculture pond in Pirojpur, Bangladesh.

Governing authorities and policymakers in wetland and fisheries management require reliable data to form a comprehensive management framework. Moreover, people need to be aware of the threats and risks of SMCF invasion into the natural waterbodies of Bangladesh. Therefore, this review discusses the general characteristics, habitat and distribution, invasion impacts, and management and utilisation aspects of SMCF globally. This review aims to provide a thorough understanding of how SMCF affects aquatic biota and habitats, how they endanger native fishes, and how they can be managed sustainably and safely. This understanding may aid policymakers in managing the potential threats and consequences of the already invaded SMCF in Bangladesh. Finally, the review suggests some necessary steps to control the SMCF invasion in Bangladesh.

Materials and Methods

A thorough literature search was conducted to identify potential threats posed by the invasion of suckermouth armoured catfish and the impacts on aquatic biodiversity, human utilisation, and management options. The literature search was conducted using several academic databases, including Google Scholar, Clarivate's Web of Science, WorldWideScience, Science.gov, Refseek, and online government databases.

A combination of keywords and Boolean operators were used to define search terms. The search terms were related to suckermouth armoured catfish and included keywords such as "suckermouth catfish," "invasion," "introduction," "spread," "range expansion," "biological control," "ecological impacts," "habitat alteration," "Loricariidae" "suckermouth catfish invasion", "impacts of suckermouth catfish invasion", "*Pterygoplichthys*", "*Hypostomus*", "*Glyptoperichthys*", "*Liposarcus*", "sailfin catfish", "armoured catfish", "invasion of suckermouth", "suckermouth catfish distribution", "suckermouth catfish habitat", "Biology of suckermouth catfish", "different species of suckermouth catfish" and "management".

Boolean operators (AND, OR, NOT) combined or excluded terms were used to reduce bias and increase search efficiency. The search was limited to peer-reviewed scientific papers, technical reports, and government records on suckermouth armoured catfish (Siluriformes: Loricariidae) from various countries, focusing on papers published between 1990 and 2023. A total of 149 papers were included in this review. The results were screened by reading each article's title, abstract, and keywords.

The articles that did not meet the inclusion criteria were excluded. The criteria were: (i) the article was relevant to suckermouth catfish invasion, (ii) the article provided original research or a comprehensive review of existing literature, and (iii) the article was published in a peer-reviewed journal or was from a reputable source. The reference lists of relevant articles were searched manually to identify additional sources that were not captured in the initial search. The reliability of the sources was assessed prior to extracting any information. Data from selected articles were extracted and organised into relevant themes. A data extraction form was used to capture all relevant information, including study location, study design, invasive species impacts, and management strategies.

Habitat, Distribution, and Invasion

There are 983 species of SMCF in the family Loricariidae (Roxo et al., 2019). They are distributed throughout tropical and subtropical areas of the world (Hoover, 2004; Orfinger and Goodding, 2018). Members of the genus *Pterygoplichthys* are native to

South America (Orfinger and Goodding, 2018). They are the most widely introduced Loricariids observed in Asia, North and Central America, the Caribbean, and Hawaii (Hussan et al., 2016).

Among the *Pterygoplichthys* members, *P. disjunctivus* (Weber, 1991) is native to Brazil, Bolivia's Rio Madeira drainage, *P. pardalis* (Castelnau, 1855) is native to the Amazon River basin, Brazil, and Peru (Page and Robins, 2006), and *P. multiradiatus* (Hancock, 1828) is native to the Orinoco River basin (Burgess, 1989). SMCFs can be found in habitats such as lakes, rivers, reservoirs, and waterways (Mendoza et al., 2009). They are found in narrow channels, river mouths, heavily contaminated water (Elfidasari et al., 2020), fast and slow-flowing streams, lowland rivers with warm water, and oxygen-depleted ponds (Chavez et al., 2006).

Although most of the available SMCFs come from the wild, they are also cultivated for aquarium trade by commercial farmers (Page and Robins, 2006). SMCFs can be divided into three ecotypes: suckers with terminal lips and a deep body that live in large lakes and slow-moving rivers; suckers with projecting plates on their lower lips that graze on algae and insects from rocks in streams; and suckers with subterminal mouths that live in a variety of hydrologic environments (Moyle, 2002). SMCFs shelter in burrows during winter (Nico and Martin, 2001). They dig holes along the river banks about the same width as the resident fish (Nico and Martin, 2001) and are 0.5 to 1.0 m in length (Devick, 1989). They can survive in the oligohaline and mesohaline waters of estuarine systems. They can stay at salinities as low as 10 PSU for up to 7 days, 1–3 days at salinities of 11–12 PSU, and up to 5 hours at salinities of 16–22 PSU (Capps et al., 2011). They can thrive in the pH range of 5.5–8.0 (Mendoza et al., 2009). Although bottom-dwelling, they breathe air at the water surface during dry seasons or at low dissolved oxygen levels (Nico et al., 2012).

SMCFs were introduced in Asia more than 30 years ago. They were observed first in the Philippines, then in Indonesia and Thailand (Weber, 1992). Different species of SMCF have been introduced in India (Seshagiri et al., 2021), Bangladesh (Hossain et al., 2008), Vietnam (Gusakov et al., 2018), Sri Lanka (Sumanasinghe and Amarasinghe, 2014), Thailand (Chaichana and Jongphadungkiet, 2012), Philippines (Chavez et al., 2006), Malaysia (Saba et al., 2020), China (Wei et al., 2017) and many other countries. Recently, *P. pardalis* was found in the Shatt al-Arab River of Iraq (Qasim and Jawad, 2022). Morphological and molecular identification of SMCF in the reservoirs and watercourses of Southern Vietnam revealed the presence of *P. pardalis*, *P. disjunctivus*, and an interspecific hybrid of these two species (Stolbunov et al., 2021).

The process of invasive fish invasion can be categorised into five distinct stages, which include: (a) the species being transported beyond its native range through human-mediated pathways, (b) the species being introduced to a new environment, (c) the establishment of a self-sustaining population, (d) the spread of the species, and (e) the impact that the invasive species has on the receiving ecosystem (Moyle and Light, 1996; Blackburn et al., 2011). Release from aquariums or escape from aquaculture facilities are the leading causes of SMCF invasion (Page and Robins, 2006). In Bangladesh, SMCFs have invaded the north and southwest floodplains of the Ganges-Brahmaputra River drainage (Hossain et al., 2018). They spread in large numbers in the Buriganga River (Newagebd, 2020), Kaptai Lake (Newagebd, 2021), and Halda River (Jugantar, 2022). They have possibly been introduced in Padma, Meghna, and many other important rivers and wetlands in Bangladesh (Newagebd, 2021). Different species of the genus *Pterygoplichthys* have been reported in 38 out of the 64 districts of Bangladesh (Mamun et al., 2023).

Sundarban mangrove wetlands are at high risk of invasion due to the discovery of SMCF in the surrounding areas of this globally significant mangrove (Suresh et al., 2019). SMCF invasion in the Halda River and Kaptai Lake can be most unfortunate for the fisheries sector in Bangladesh. The Halda River is the natural spawning ground, and gene bank of native carp species (Saimon et al., 2016; Podder et al., 2017), and the Kaptai Lake is one of the largest man-made lakes in South Asia that is equally important for fish production, aquatic ecology, and the environment (Rahman et al., 2014). Hossain et al. (2008) reported the first record of *P. multiradiatus* in Bangladesh. Later, *P. anisitsi* and *P. pardalis* were found in natural waterbodies, aquaculture ponds, and wetlands (Newagebd, 2020; Newagebd, 2021). However, the actual scenario of SMCF invasion, species types, and distribution in Bangladesh has not yet been assessed. Thus, an invasion assessment is necessary for different waterbodies and areas. Areas of high abundance and risk should be determined, zoned, and categorised to ensure proper management.

Morphological Features

The body shape of SMCFs is flat-bottomed (Walker, 1968) with a cover of three or more rows of boney plates (Page and Burr, 1991). They have a pair of subterminal barbells, sucking lips, and an adipose fin with spines on the front side. The mouth is smaller than the surrounding lips, forming a sucking disc. Ventrally, the caudal fin is usually longer than dorsally, and pectoral fins are solid and spinous (Walker, 1968). They have light-adjusting lunate pupils in their eyes (Page and Burr, 1991), an expanded iris operculum, and a retina devoid of double-cone cells (Douglas et al., 2002).

Species-level identification of SMCF is difficult because the taxonomy is very primitive, there is confusion among genera (Armbruster, 2004), and frequent hybridisation (Krishnakumar et al., 2009). Confusion may arise between the *Hypostomus* and *Pterygoplichthys* while *identifying the introduced* SMCFs in Bangladesh. Members of the *Hypostomus* and *Pterygoplichthys* differ significantly (Burgess, 1989). *Hypostomus* members have a short dorsal fin, fewer than nine dorsal fin rays, a smooth margin in the snout, a spotted pattern, and fused opercular bones. On the other hand, *Pterygoplichthys* members have a comparatively larger dorsal fin, more than 10 dorsal fin rays, a granular snout, and articulated interopercular bone with avertable spines (Burgess, 1989).

Species of the genus *Pterygoplichthys* are morphologically similar, but colouration varies among species (Page, 1994). Dorsal, ventral, and lateral marks can be used to differentiate among species (Page, 1994; Armbruster, 2004). The four species, *P. pardalis*, *P. multiradiatus*, *P. disjunctivus*, *and P. anisitsi*, have very similar appearances (Page and Burr, 1991; Page and Robins, 2006) but are distinguishable based on their abdominal patterns (Nico et al., 2012). *Pterygoplichthys pardalis* has spotted abdomens, whereas *P. disjunctivus* has vermiculated abdomens (Rao and Sunchu, 2017). Among these four related species, only *P. multiradiatus* has an uncoalesced dark spot pattern on a light background (Page and Robins, 2006). The mean total length of *P. pardalis*, *P. multiradiatus*, and *P. disjunctivus* was 25.2 cm (Bandara et al., 2021), 18.2 cm (Rao and Sunchu, 2017), and 28.8 cm (Meena et al., 2016) respectively. Proper identification at the species level is essential for creating a species database of SMCFs that have invaded Bangladesh. Because of hybridisation, molecular level identification is preferable to resolve confusion among different species.

Biological Features

Growth and reproduction

SMCFs can live for more than 10 years in their native range (Hussan et al., 2016) and mature at 12 months of age (Winemiller, 1989) at a size of 40–50 cm (Burgess, 1989). They grow rapidly in the first two years of life and reach a total length of more than 35 cm (Devick, 1991). According to the gonadosomatic indices, the reproductive season of *Pterygoplichthys* spp. runs from May to September (Mazzoni and Caramaschi, 1997). They spawn multiple times, have a variety of oocyte sizes (Gibbs et al., 2008), and are highly fecund, with 472–1283 mature eggs/female (Devick, 1991). During the spawning season, adult females are often more vigorous and plentiful than adult males (Gibbs et al., 2008). They excavate 120–150 cm deep burrows in streams or pond banks (Burgess, 1989), where females deposit eggs and males guard the developing mass of eggs until they hatch free-swimming larvae (Hussan et al., 2016).

Food and feeding

SMCFs are commonly known as herbivores and janitors based on their preference for food items (Hoover, 2004). Despite interspecific diversity in food preferences, detrital matter and plant components predominate the stomach of SMCF (Mendoza et al., 2009; Pound et al., 2011; Suresh et al., 2019). They have a consistent mouth and gut architecture, including a rasping mouth with numerous teeth and a long gut (Pound et al., 2011). With thick-lipped and toothy mouths, they eat benthic aquatic plants and phytoplankton, scrap off plant components or suck up fine sediments at the bottom of waterbodies. The stomach contents of SMCF are shown in Table 1.

Adaptive Features

SMCFs have a variety of adaptations that allow them to survive in extreme environment, food scarcity, and predation risks (Graham and Baird, 1982). They can thrive in eutrophic conditions, high water velocities, and brackish water, and travel overland under harsh climatic conditions (Walker, 1968). SMCFs can survive under dewatered conditions. For example, SMCFs in the San Antonio River appeared "dead" in dry burrows but were alive and quickly recovered when released back into the water (Nico and Martin, 2001). They are tolerant of eutrophic environments and other forms of aquatic nuisance, as is evident in Florida's eutrophic Lake Thonotosassa, Lake Maggiore (Page,

Table 1. Stomach content of the members of the genus *Pterygoplichthys*.

Species	Stomach content	Reference
Pterygoplichthys disjunctivus (Weber, 1991)	56 % detrital matter, 11 % plant matter, 11 % fish eggs, 5 % polychaete worms, and other unidentified matters	(Suresh et al., 2019)
Pterygoplichthys multiradiatus (Hancock, 1828)	Plants and detritus with less than 1 % of crustaceans, insects, molluscs, and arachnids	(Gestring et al., 2010)
Pterygoplichthys pardalis (Castelnau, 1855)	Bacillariophyceae (41.19 %), Cyanophyceae (53.54 %), and small fishes	(Tisasari et al., 2016)
Pterygoplichthys pardalis	Detritus (28 %), algae (14.11 %), insect larvae (15.53 %), crustacea (14.12 %), fish (7.06 %), cyprinid eggs (7.06 %); other fish eggs and larvae (7.06 %) and rotifer (2.82 %)	(Qasim and Jawad, 2022)

1994), and the highly polluted and oxygen-poor Buriganga River in Bangladesh (Newagebd, 2020). They can withstand changes in water quality and even survive in effluent treatment plants (Nico and Martin, 2001). A large amount of yolk in their eggs helps them develop their embryos directly into juveniles without actual metamorphosis. This makes them more competitive with other aquatic animals in the early stages of life (Hoover et al., 2014). SMCF have a large, vascularised stomach that allows them to breathe air during hypoxia (Graham and Baird, 1982; da Cruz et al., 2009). They can use their stomach lining to carry oxygen during feeding (Hoover, 2004).

The cold tolerance of SMCF is not evident, but they can relocate their communities during winter (Nico and Martin, 2001). High glucose and lactate levels in the blood circulation help to maintain or enhance the heart rate during hypoxia (MacCormack et al., 2003). SMCFs show a visible defence posture when predators threaten them and can resist predators to swallow them by raising fin spines (Grier, 1980). They have external bony plates that protect them from predators (Liang et al., 2005)). The lunate pupils in their eyes help them to camouflage (Douglas et al., 2002). Such adaptive features may allow them to dominate native and small indigenous species (SIS) of fish in the critical aquatic habitats of Bangladesh. These features may also pose challenges in managing SMCF invasion in the natural waterbodies and wetlands of Bangladesh.

Threats and Impacts of Invasion

SMCF invasion can significantly affect aquatic ecosystems and habitats (Hoover, 2004; Hubilla et al., 2007; Nico et al., 2009; Capps and Flecker, 2013; Rubio et al., 2016), native fish and aquatic species (Hubbs et al., 1978; Hoover et al., 2004; Hastings et al., 2006) and fisheries sector (Escalera-Vázquez et al., 2019; Seshagiri et al., 2021). This review discusses some effects in the following sections.

Impact on aquatic ecosystem, habitat, and fauna

Establishment of SMCF in any waterbody affects biogeochemical cycles, nutrient dynamics, and ecosystem functionality (Hoover, 2004; Rubio et al., 2016). They cause premature shifts in nutrients from the food web and reduce nutrient availability for essential consumers in aquatic ecosystems (Werner, 1982). Their thick bony plates serve as phosphorus sinks in oligotrophic environments and may reduce primary and secondary productivity (Englund, 2000). SMCF excavates stream bottoms, uproots aquatic plants, reduces native plant abundance, and creates surface covers that prevent sunlight penetration in waterbodies (Walker, 1968; Hubilla et al., 2007). They can alter aquatic insects and arthropods' food chains and natural environments (Inger and Chin, 2002).

Fast maturation, high population density, and long lifespan of SMCFs help them dominate over other aquatic lifeforms (Englund, 2000). They disturb aquatic biota through physical disturbances and reduce food availability by grazing on algae and detritus (Hoover et al., 2014). Their grazing behaviour hampers food sources and shelter for aquatic insects (Walker, 1968), causing turbidity (Hoover, 2004), sediment resuspension, and substrate size alteration (Walker, 1968). SMCFs burrow river banks for shelter and cause erosion, benthic habitat alteration (Hoover, 2004), and siltation (Nico et al., 2009). They form large spawning groups in the burrows, hamper shoreline stability, and increase the suspended sediment load in the water column (Nico, 2000). For example, the *P. multiradiatus* population was established in the Wahiawa Reservoir of Oahu, Hawaii, in 1986 and created thousands of burrows within two years of establishment (Devick, 1991).

Impact on other fish and aquatic species

SMCFs can displace other aquatic species, decrease suitable habitats (Flecker, 1992) and endanger keystone predator populations (Hoover, 2004). Their invasion may affect aquatic prey-feeding organisms and fish (Englund, 2000). They have competitive advantages over smaller, short-lived, less tolerant, and low-fecund fish, threatening their abundance (Hubbs et al., 1978). Several studies have documented the role of SMCFs in native fish displacement both directly and indirectly through food and habitat competition (Bunkley-Williams et al., 1994; Chavez et al., 2006; Chaichana et al., 2011). They actively compete with native aquatic species and may accidentally consume fish eggs (Hoover, 2004). For example, *P. multiradiatus* was found to prey on cichlid eggs in Sri Lankan waterbodies (Amarasinghe et al., 2006). Their abundance in introduced waterbodies may negatively affect the growth, maturation, and reproduction of native fish (Wei et al., 2022).

Defensive spine erection of SMCFs presents serious threats to shorebirds attempting to ingest them (Bunkley-Williams et al., 1994). Their introduction affects fish and shrimp production, resulting in the loss of capital and people's livelihoods (Chavez et al., 2006; Krishnakumar et al., 2009). The presence of SMCF leads to unintentional entanglement in commercial gillnets and thus reduces the effectiveness of gillnets in catching target fish species (Wijesinghe et al., 2021). The introduction of SMCF could potentially pose risks of disease or parasite transmission. In a reservoir located on Okinawa Island in southern Japan, a dactylogyrid monogenean parasite known as *Heteropriapulus heterotylus* (Jogunoori, Kritsky and Venkatanarasaiah, 2004; Kritsky, 2007) was discovered in the gills of *P. disjunctivus* (Nitta and Nagasawa, 2013).

All of the abovementioned impacts of SMCF invasion may bring similar dangers to invaded rivers, wetlands, and aquatic habitats in Bangladesh. SMCF population establishment and expansion may threaten the existence of native and small indigenous species (SIS) of fish and the sustainability of fish production. Sixty-four freshwater fishes in Bangladesh are already threatened (IUCN, 2015). The invasive effects of SMCF may lead to the extinction of these threatened species in important freshwater habitats. Aquatic habitats, nursing grounds, spawning grounds, ecologically critical areas, sanctuaries, and other crucial areas for fish and aquatic animals may be in peril if management measures are not implemented as soon as possible. Table 2 provides an overview of the impact of SMCF invasion in different countries.

Table 2. Effects of suckermouth armoured catfish invasion in different countries.

Introduced species	Place of introduction	Effects/ Concerns	Reference
Pterygoplichthys spp.	Andhra Pradesh, India.	Reduction of carp production by 18.88 % to 22.92 %, increased FCR (Feed Conversion Ratio) by 25.76 % in aquaculture ponds, and financial loss of fish farmers	(Seshagiri et al., 2021)
Pterygoplichthys spp.	Three southern provinces of Central Vietnam	Intrusion into major river basins was confirmed by capturing specimens from nine distinct waterbodies and channels across various locations	(Gusakov et al., 2018)
Pterygoplichthys disjunctivus (Weber, 1991)	Cauvery River System, Tamil Nadu, South India	Reduction of native fish availability, including Murrel (*Channa striata*, Bloch, 1793) and other Carps (*Cirrhinus cirrhosus*, Bloch 1795, *Catla catla*, Hamilton, 1822, *Labeo rohita*, Hamilton, 1822)	(Meena et al., 2016)
Pterygoplichthys pardalis (Castelnau, 1855)	Polgolla reservoir, Sri Lanka	Negative impact on the commercial production of Cichlids	(Sumanasinghe and Amarasinghe, 2014)
Pterygoplichthys spp.	Sri Lanka	Have become a common catch over native species in many inland reservoirs	(Wijesinghe et al., 2021)
Pterygoplichthys pardalis	Thailand	Found to consume the eggs and fry of Nile tilapia (*Oreochromis niloticus*, Linnaeus, 1758) in aquaria	(Chaichana and Jongphadungkiet, 2012)
Pterygoplichthys spp.	Balsas Basin, Mexico	Observed burrowing the nests of blue tilapia (*Oreochromis aureus*, Steindachner, 1864) and the resulting reduction in their population	(Hoover et al., 2014)
Pterygoplichthys pardalis	Philippines	Reduced abundance of native fish species	(Chavez et al., 2006)
Pterygoplichthys spp.	Estuarine regions of the South and West Shores of Oahu, Hawaii	Disturbed the existence of native species	(Englund, 2000)
Pterygoplichthys multiradiatus (Hancock, 1828)	Lake Okeechobee, Florida, USA	Caused a significant reduction in the native fish abundance	(Mendoza-Alfaro et al., 2009)
Pterygoplichthys disjunctivus (Weber, 1991)	Asi River, Turkey	Competition with cyprinid species and benthic grazers	(Özdilek, 2007)
Pterygoplichthys spp.	Association of Southeast Asian Nations (ASEAN) member countries	Adverse effects on the native Cyprinid population	(Phillips et al., 2004)
Pterygoplichthys spp.	Infiernillo Reservoir, Mexico	Decreased abundance of a native catfish (*Ictalurus balsanus*, Jordan and Snyder, 1899) and declined Tilapia production	(Mendoza-Alfaro et al., 2009)
Pterygoplichthys spp.	Florida, USA	Reduced catch per unit effort (CPUE) of recreational fishes	(Mendoza-Alfaro et al., 2009)
Pterygoplichthys multiradiatus	Fresh waterbodies, Puerto Rican, Caribbean Island	Twenty brown pelicans (*Pelecanus occidentalis*, Linnaeus, 1766) were asphyxiated upon swallowing and many others died	(Bunkley-Williams et al., 1994)
Pterygoplichthys disjunctivus	Volusia Blue Spring, Florida	Stress the endangered "Florida Manatee" (*Trichechus manatus latirostris*, Harlan, 1823) by attaching to them and disturbing their regular behaviour including respiration rate and activity level	Gibbs et al. (2010)

Table 2. Continued.

Introduced species	Place of introduction	Effects/ Concerns	Reference
Pterygoplichthys pardalis, *Pterygoplichthys disjunctivus* and their hybrids	Chumpan River, Southeastern Mexico	Raised concerns of dispersal to other waterbodies and subsequent adverse impacts on their ecosystem	(Álvarez-Pliego et al., 2015)
Pterygoplichthys ambrosettii (Holmberg, 1893)	Paraná River, South America	First documented in the floodplain of the Upper Paraná River in 2000 and has since spread to 118 different locations	(da Silva et al., 2022)
Pterygoplichthys pardalis	Gayathripuzha River, Kerala, India	Led to the alterations of the river ecosystem and disruptions in the composition of native fish species	(Veena et al., 2023)
Pterygoplichthys spp.	Agusan River, Philippines	Created numerous breeding burrows along the riverbank, leading to bank erosion, hydrology alterations, and river ecosystem disturbance	(Almadin et al., 2016)

Management Strategies

The management of fish invasions involves a variety of techniques that depend on the stage of the invasion. Prevention, early detection, risk assessment, monitoring, eradication, containment, and suppression are successful strategies for controlling the invasion of non-native fish species (Robertson et al., 2020; Bernery et al., 2022). Prevention and early response are considered the most effective and economical ways to manage invasive non-native species (Leung et al., 2012). Control and eradication techniques become necessary when the invasion is at an advanced stage (Robertson et al., 2020). Various traditional techniques are available to prevent SMCF invasion into waterbodies. These techniques include netting, trapping, bank stabilisation of waterbodies, and diversion of waterways (Hoover, 2004).

Physical barriers such as screens and mesh fences can effectively prevent the movement of SMCF into new waterbodies (Hussan et al., 2021). Mesh fences can be installed to block waterways and hinder the movement of fish upstream or downstream (Scott et al., 2012). For aquaculture ponds, mechanical traps, strong and wired nets, screens, and dams can be used to prevent the intrusion of SMCF. Another effective technique is to expose the ponds to sunlight after dewatering them (Hussan et al., 2021; Qasim and Jawad, 2022). To reduce the intentional release of SMCF into natural waterbodies, strict regulations, and awareness generation are required (Hossain et al., 2008; Ishikawa and Trachihara, 2014; Mogalekar et al., 2017). It is necessary to educate the public on the hazards of releasing aquarium fish into natural waterbodies and encourage responsible disposal of unwanted aquarium fish. Public awareness campaigns, educational programmes in schools and public places, and social media campaigns can be useful in achieving this goal (Qasim and Jawad, 2022). It is essential to regulate their imports and sales in the pet trade industry to prevent the invasion of SMCF. Countries and regions can establish regulations that prohibit the importation and sale of invasive species, including SMCF, and impose penalties for violators to reduce the likelihood of new introductions and limit the spread of existing populations (Leung et al., 2012). Regulations must be formulated by considering the risks associated with the ornamental trade, commercial practises, research, and import for human consumption. The regulations should specify a consistent and transparent process for evaluating a proposed new introduction, including a detailed biological background and risk assessment (ICES, 2005). Accurate species identification is crucial for effective monitoring, management, and understanding of the invasion strategies of exotic species in a new ecosystem. To achieve this, the standard DNA barcode approach effectively distinguishes invasive fish species with similar morphologies (Armstrong and Ball, 2005). This method is essential for comprehending the invasion strategies of exotics in a novel ecosystem (Jumawan et al., 2011).

Besides traditional identification, advanced methods like environmental DNA (eDNA) analysis can be used to detect invasion and identify the invaded species (Manfrin et al., 2019). The development of a comprehensive risk assessment protocol can ensure the development of an efficient invasion management strategy. The assessment protocol should consider the population parameters, reproductive features, and biomass status to determine the potential harm posed by the invader (Rueda-Jasso et al., 2013; Ju et al., 2020). Then, habitat-specific management steps should be designed for invaded ecosystems (N'Guyen et al., 2016; Wei et al., 2022). Public information from social media and online platforms may offer promising tools for early detection and rapid response to invasive fish species. For instance, the public can use mobile phone applications to monitor, track, identify, and obtain information about invasive species (Howard et al. 2022). Collaboration between scientists and journalists, as well as governmental and organisational bodies, has the potential to enhance their ability to track the distribution of non-native species in Bangladesh. This could result in the development of cost-effective programmes that raise public awareness of the impact of SMCF (Mamun et al., 2023).

Intensive harvesting practises, regular removal in invaded areas, and harvesting smaller individuals are recommended to eradicate invasive species quickly (Chaichana and Jongphadungkiet, 2012; Raj et al., 2020). Negotiating with commercial fishermen, increasing sport fishing activities in invaded areas, and creating a financial reward system to motivate local people to catch SMCF can be possible management options (Hoover, 2004; Qasim and Jawad, 2022). For example, repetitive removal of SMCF by hand and spears effectively reduced the occurrence of SMCF in the Rainbow River, Florida (Hill and Sowards, 2015).

The use of ichthyocides, and the removal of egg masses and juveniles can also help to reduce the reproductive success and propagation of invasive fish (Power, 1984). Chemical treatments, such as rotenone, have been widely used for rapid and efficient eradication, but they can be toxic to non-target species (Dalu et al. 2015). Physical or nonphysical barriers can be used to contain species and suppression actions, such as selective capture, can be promoted through public awareness and incentives (Robertson et al., 2020). Increasing native fish populations in invaded waterbodies can also suppress the invaded fish (Hoover, 2004). Exploiting invasive fish as a food source can be an effective suppression technique (Seaman et al., 2022).

Harvesting suckermouth catfish from rivers has proven to control their invasion in various regions effectively (Hay et al., 2022). For example, in the San Marcos River, Texas, controlling the invasion of SMCF was attempted by increasing fishing pressure. This method resulted in a mortality rate of SMCF that was 1.50 to 1.75 fold higher than natural mortality (Blanton et al., 2020). However, implementing eradication approaches on a large scale is challenging (Havel et al., 2015). Therefore, it is preferable to use local and community-level control efforts to reduce the abundance of invasive fish. When eradication becomes impossible, the management should focus on mitigating the impacts of invasion (Frazer et al., 2012; Hill and Sowards, 2015).

It is not recommended to incentivise aquaculture and commercial production of SMCF due to their invasive nature and associated ecological and economic impacts (Haubrock et al., 2022). The FAO (1995) suggests a precautionary approach that would limit the use of alien species in aquaculture and promote the development of native stocks. The use of different alien species in aquaculture has been proven to be invasive, leading to adverse and irreversible impacts on the native environment. Therefore, governments and regulatory bodies should evaluate the short-term benefits to society against the potential long-term impacts on economic, social, cultural, and natural environments when justifying the use of alien species in aquaculture (FAO, 1995; ICES, 2005). The escape of invasive fish, including SMCF, from aquaculture facilities is a global concern (FAO, 2016). Although limited statistics make assessing the number and magnitude of escapes challenging, many have occurred worldwide (Thorvaldsen et al., 2015), particularly in developing countries (Gao et al., 2017).

Invasive fish, including SMCF, can negatively affect the biodiversity and ecological functions of the native ecosystems (Vitule et al., 2009). Their invasion can lead to the loss of biodiversity, degradation of ecosystems, and even extinction of endemic species through direct competition or predation (Naylor et al., 2001). For example, the release of *Pterygoplichthys* spp. from fish farms in Thailand resulted in extensive harm to aquatic plants, a decline in water quality, and a decrease in native biodiversity (Hubilla et al., 2007; Chaichana and Jongphadungkiet, 2012). Invasion of alien species like SMCF can also cause genetic pollution, leading to a decrease in genetic diversity, changes in population structure, and ultimately, the extinction of native species (Ju et al., 2020). According to the International Union for Conservation of Nature (IUCN), the ecological impacts of invasion are often immense, insidious, and irreversible (IUCN, 2000).

Developing countries like Bangladesh must implement effective policy and management measures to promote sustainable aquaculture and protect biodiversity. This includes enacting comprehensive legislation, establishing agencies, and setting national standards for preventing, monitoring, and controlling invasive species (Ju et al., 2020). Integrated research and education are also necessary to enhance risk assessment, prevention, and management of invasive species to achieve these goals (Wei et al., 2019). It is essential to have a comprehensive understanding of available literature, life-history data, and control methods to develop a sustainable management plan for SMCF invasion. The effectiveness of each management strategy should be evaluated, and the best option should be selected (Donaldson and Cooke, 2016).

Utilisation

SMCFs are widely imported into various countries because of their distinctive appearance, tolerance, and ability to remove algae from submerged surfaces (Hoover, 2004). Creating market demands for these invasive species may be a cost-effective solution for their invasion. However, utilisation should be targeted to reduce the number of invaded fish in waterbodies, not to culture them for revenue (Varble and Secchi, 2013). This review discusses the current and potential uses of SMCF. These utilisation options may be helpful to managerial bodies and researchers in Bangladesh.

Food

SMCFs are commercially beneficial for flesh and roe (Hoover, 2004). They are nutritious and high in protein, carbohydrates, and omega-6 fatty acids (Mengumphan and Saengkrachang, 2008). There are approximately 30.62 ± 2.98 % edible flesh portion of the total weight of *P. multiradiatus*, 33.70 % polyunsaturated fatty acid (PUFA), and 12.99 % docosahexaenoic acid (DHA) in the fatty acid composition (Ariyarathna et al., 2014). *Pterygoplichthys disjunctivus* contains 81.14 % moisture, 16.1 % crude protein, 1.03 % crude fat, and 0.9 % ash in their chemical composition (Mohanty et al., 2017). The mature roe of *P. disjunctivus* has high protein (26.0 ± 1.5) and lipid (8.2 ± 0.7) percentages (Guillén-Sánche et al., 2015). However, safety issues may arise when SMCF is used as human food.

Several studies analysed heavy metal concentrations in SMCF as a safety issue for human consumption. For instance, Elfidasari et al. (2018) found higher Pb, Hg, and Cd concentrations than the safe limit in *P. pardalis*, whereas Ariyarathna et al. (2014) found safe concentrations of Hg, Pb, and Cd in *P. multiradiatus*. Other concerns may be their irritating appearance, smell, and rigid bone formation (Sumanasinghe and Amarasinghe, 2014). There is a scope of research on proximate composition determination, heavy metal analysis, and acceptability issues of SMCF as foods in Bangladesh.

Commercial fishmeal

SMCFs are suitable for preparing fishmeal alternatives (Sumanasinghe and Amarasinghe, 2014; Panase et al., 2018; Abesinghe et al., 2020) and protein sources (de Fonseka and Radampola, 2022) for fish (Panase et al., 2018), chicken (Intawicha et al., 2020) and duck feed (Indarsih et al., 2016). Processing SMCF to prepare fish meal may be an effective method to reduce their population in natural waterbodies (Mengumphan and Saengkrachang, 2008; de Fonseka and Radampola, 2022). There are sufficient nutrients in *P. pardalis* meal for fish growth (Abarra et al., 2017). Proximate composition of *P. multiradiatus* meal is quite similar to the commercial fish meal with 69.5 ± 0.04 % crude protein, 4.5 ± 0.05 % crude lipid, 6.0 ± 0.2 % moisture, and 10.6 ± 0.2 % ash content (de Fonseka and Radampola, 2022). SMCF meal can substitute a commercial fish meal with no statistically significant difference ($p > 0.05$) in weight gain, average daily growth, specific growth rate, feed conversion ratio, feed efficiency, and protein efficiency ratio (Millamena, 2002).

SMCF meal does not negatively affect fish growth, body weight, or food consumption (Asnawi et al., 2015). For example, a feeding trial of SMCF meal on Mekong giant catfish (*Pangasianodon gigas*, Chevey, 1931) showed a positive output without affecting growth performance and feed utilisation (Panase et al., 2018). In Thailand, replacing 25–50 % of fish meals with SMCF meals resulted in better growth performance and meat quality (Intawicha et al., 2020). Moreover, using SMCF meal in duck feed as a protein source can be beneficial (Indarsih et al., 2016).

Approximately 70 % of aquaculture production requires high-protein feed from fish meal and fish oil (Hua et al., 2019), and the feed cost is the highest in fish farming (Bakİ and Yücel, 2017). Researchers and managerial bodies in Bangladesh can assess the suitability of SMCF for fishmeal preparation. Such efforts may be incredibly beneficial for reducing the dependency on traditional protein sources for fish feed. Most importantly, it may help increase the utilisation of invaded SMCF in Bangladesh.

Value added products and byproducts

Several studies have suggested the preparation of value added products and byproducts from SMCF (Rueda-Jasso et al., 2013; Ariyarathne et al., 2016; Herath et al., 2020; Puspitasari et al., 2021; Wijesinghe et al., 2021). The invasion of SMCF in the natural waterbodies of Bangladesh is alarming and may have severe consequences. Therefore, preparing such products from SMCF may be helpful as a management option in Bangladesh. The safety issues and public acceptance in Bangladesh should be considered before making such products from SMCF. Some examples of value-added products and byproducts from SMCF are shown in Table 3.

Wastewater biotreatment

Wastewater treatment is becoming increasingly important because of declining water resources and increasing industrial effluents (Dixit et al., 2011). SMCFs can be suitable candidates for the biotreatment of wastewater (Kumar et al., 2016; Karthiga et al., 2019). For example, the use of *P. pardalis* to biotreat sugar industry effluents showed good performance with a gradual reduction in total dissolved solids (TDS), total suspended solids (TSS), water hardness, total alkalinity, biochemical oxygen demand (BOD), chloride ions, ammonia, sulphates, nitrates, and phosphorus levels (Karthiga et al., 2019).

As a natural coagulant, meals of *Pterygoplichthys* spp. showed 30 % effectiveness in eliminating turbidity from fish farm effluent (Castillo et al., 2022). *Pterygoplichthys pardalis* effectively reduced dissolved solid levels, total alkalinity, and pH in dairy farm effluents (Geetha and Thatheyus, 2019). It is important to be cautious when using non-native species as biological control agents due to potential ecological consequences (Copp et al., 2005).

Common management strategies to reduce SMCF invasion in Bangladesh may be challenging without a

Table 3. Value-added products and byproducts from suckermouth armoured catfish.

Product Type	Comment	Reference
Fish biscuits	No noticeable difference in sensory properties with traditional flour-made biscuits. High protein and unsaturated fatty acid content, and safe for consumption	(Ariyarathne et al., 2016)
Bone flour from *Pterygoplichthys pardalis* (Castelnau, 1855)	Contained 25.04 % protein, 10.48 % lipid, 0.66 % moisture, 59.46 % ash, and 4.35 % carbohydrates	(Puspitasari et al., 2021)
Acid-soluble collagen from *Pterygoplichthys disjunctivus* (Weber, 1991)	Collagen was extracted from skin, flesh, bone, and fin. Flesh and skin were recommended as good candidates for industrial uses	(Herath et al., 2020)
Bioactive fish protein hydrolysates from *Pterygoplichthys pardalis* (Castelnau, 1855)	Found antioxidant activities, iron-binding function, and antimicrobial properties	(Wijesinghe et al., 2021)

proper record of invasion, current status, and risk assessment. Therefore, managerial bodies can adopt different utilisation options in addition to control measures. However, it is imperative to implement appropriate safety, monitoring, and control measures in SMCF aquaculture and seed production intended for both the ornamental trade and the food market in Bangladesh.

Management Recommendations for Bangladesh

The Bangladesh Government has already imposed restrictions on the imports and sales of the suckermouth catfish group to prevent its further spread (MoFL, 2023). The Bangladesh Fisheries Research Institute (BFRI) has taken active measures, such as conducting public awareness campaigns and destroying illegal breeding sites, to control the population of the suckermouth catfish and prevent its spread. However, more pragmatic steps are necessary to reduce the impacts on the aquatic ecosystem and fisheries sector. Thus, the review recommends some necessary measures to minimise the threats of SMCF invasion in Bangladesh.

Figure 2 outlines various approaches for identifying, monitoring, and managing invasive species in aquatic ecosystems. The first step is to identify areas of invasion and categorise them based on risk and susceptibility. Geographic information systems can help map out these regions. The taxonomic identification of the invasive species using morphological and molecular methods is also important. Direct observation and periodic surveys in the invaded areas can provide critical information on the species' behaviour and potential impacts. Impact and risk assessments using predictive modelling can help understand the consequences of invasion in the ecosystem.

Creating a database of occurrences, types, and possible impacts can aid in decision-making for management strategies. Suitability analysis of the

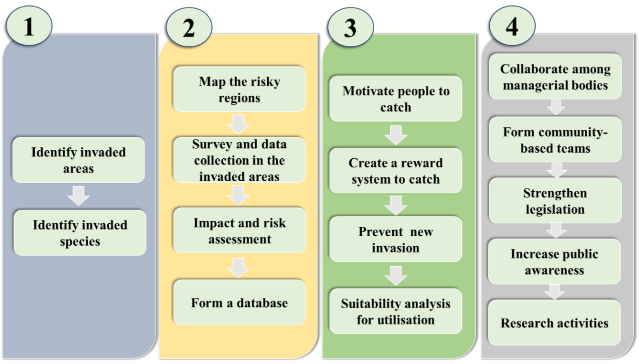

Fig. 2. Management measures to reduce the effect of suckermouth armoured catfish invasion in Bangladesh.

invaded species for utilisation as food, value-added products, by-products can provide a potential economic benefit besides invasion control. Community-based teams can be formed to catch and destroy invaders and report any new invasions to the concerned authority. Fishermen can also be motivated to catch and destroy invasive species ethically through a reward system. Overall, these approaches can aid in managing the spread and impacts of invasive species in aquatic ecosystems.

Conclusion

Suckermouth armoured catfish invasion is an emerging threat to aquatic ecosystems, native fish biodiversity, and fishery production. Understanding the worldwide impacts, management, and utilisation aspects of this review may be helpful for managers and researchers. This review's information may help them formulate a sustainable management framework to reduce the impact of the suckermouth armoured catfish invasion in Bangladesh.

Acknowledgements

The authors are grateful to Inkiad Ahmed Himel for his assistance with the graphical aspects of this paper. The authors thank the Chattogram Veterinary and

Animal Sciences University (CVASU) for technical support. Finally, the authors thank the reviewers for their valuable comments and suggestions that helped the paper to be better and accepted by the journal. The authors received no funding for the research.

Conflict of interest: The authors declare that they have no conflict of interest.

Author contributions: Antar Sarkar: Conceptualization, data curation, methodology, writing, review and editing. Saifuddin Rana: Data curation, writing, review and editing. Pranta Bhowmik: Conceptualization, methodology, investigation. Md. Nazmul Hasan: Revision and editing. Shahida Arfine Shimul Revision, review and editing. Sk. Ahmad Al Nahid: Conceptualization, supervision, revision, review and editing.

References

Abarra, S.T., Velasquez, S.F., Guzman, K.D.D., Felipe, J.L.F., Tayamen, M.M., Ragaza, J.A. 2017. Replacement of fishmeal with processed meal from knife fish *Chitala ornata* in diets of juvenile Nile tilapia *Oreochromis niloticus*. Aquaculture Reports 5:76–83. https://doi.org/10.1016/j.aqrep.2017.01.001

Abesinghe, A., Sudasinghe, H., Amarasinghe, A., Fareed, F., Senavirathn, T., Meegaskumbura, M. 2020. The identity of the exotic *Pterygoplichthys* sailfin catfishes in Sri Lanka (Teleostei:Loricariidae). Zootaxa 4852:145–150. https://doi.org/10.11646/zootaxa.4852.1.10

Almadin, F.J.F., Jumawan, J.C. 2016. Description of breeding burrows of janitor fish (*Pterygoplichthys* spp.) in Agusan River, Butuan City, Philippines. International Journal of Advances in Chemical Engineering and Biological Sciences 3:187–190. http://dx.doi.org/10.15242/IJACEBS.AE0516116

Álvarez-Pliego, N., Sánchez, A.J., Florido, R., Salcedo, M.Á. 2015. First record of South American suckermouth armored catfishes (Loricariidae, *Pterygoplichthys* spp.) in the Chumpan River system, Southeast Mexico. BioInvasions Records 4:309–314. http://dx.doi.org/10.3391/bir.2015.4.4.14

Amarasinghe, U.S., Shirantha, R.R.A.R., Wijeyaratne, M.J.S. 2006. Some aspects of ecology of endemic freshwater fishes of Sri Lanka. In: The fauna of Sri Lanka: status of taxonomy, research and conservation, Bambaradeniya, C.N.B. (Ed), The World Conservation Union, Sri Lanka and the Government of Sri Lanka, pp. 113–124. https://portals.iucn.org/library/sites/library/files/documents/2006-030.pdf

Ariyarathna, D.S., Ahmad, S.B.N., Jinadasa, B.K.K.K., Wickramasinghe, I., Jayawardena, J.H.K. N. 2014. Evaluation of importance of Orinoco sailfin catfish (*Pterygoplichthys multiradiatus*) as a food source. Conference presentation, 17th International Institute of Fisheries Economics and Trade (IIFET) Conference, July 7–11, 2014, Brisbane, Australia.

Ariyarathne, D.S., Gamage, N., Wickramasinghe, I., Paththuwe Arachchi, M.J. 2016. Development of a fish base biscuit using Orinoco sailfin catfish (*Pterygoplichthys multiradiatus*). In: Proceedings of the National Aquatic Resources Research and Development Agency (NARA), Colombo, Sri Lanka, pp. 133–135. http://dr.lib.sjp.ac.lk/handle/123456789/5663

Armbruster, J.W. 2004. Phylogenetic relationships of the suckermouth armoured catfishes (Loricariidae) with emphasis on the Hypostominae and the Ancistrinae. Zoological Journal of the Linnean Society 141:1–80. https://doi.org/10.1111/j.1096-3642.2004.00109.x

Armstrong, K.F., Ball, S.L. 2005. DNA barcodes for biosecurity: invasive species identification. Philosophical Transactions of the Royal Society of London 360:813–1823. https://doi.org/10.1098/rstb.2005.1713

Asnawi, A., Osfar, S., Eddy, S., Suyadi, S. 2015. Potency of Sapu-Sapu fish (*Hypostomus plecostomus*) as feed supplement for local ducks. International Journal of Poultry Science 14:240–244. https://doi.org/10.3923/ijps.2015.240.244

Baki, B., Yücel, S. 2017. Feed cost/production income analysis of seabass (*Dicentrarchus labrax*) aquaculture. International Journal of Ecosystems and Ecology Science (IJEES) 7:859–864.

Bandara, K.S.N., Kumara, P.A. 2021. Morphological differentiation of suckermouth armoured catfish, genus *Pterygoplichthys* (Siluriformes: Loricariidae) in Sri Lankan freshwaters. Iranian Journal of Ichthyology 8:286–293. https://doi.org/10.22034/iji.v8i4.487

Bernery, C., Bellard, C., Courchamp, F., Brosse, S., Gozlan, R.E., Jarić, I., Leroy, B. 2022. Freshwater fish invasions: A comprehensive review. Annual Review of Ecology, Evolution, and Systematics 53:427–456. https://doi.org/10.1146/annurev-ecolsys-032522-015551

Blackburn, T.M., Pyšek, P., Bacher, S., Carlton, J.T., Duncan, R.P., Jarošík, V., Wilson J.R.U., Richardson. D.M. 2011. A proposed unified framework for biological invasions. Trends in Ecology & Evolution 26:333–339. https://doi.org/10.1016/j.tree.2011.03.023

Blanton, C.S., Perkin, J.S., Menchaca, N., Kollaus, K.A. 2020. A gap in the armor: spearfishing reduces biomass of invasive suckermouth armored catfish. Fisheries 45:293–302. https://doi.org/10.1002/fsh.10410

Bunkley-Williams, L., Williams Jr, E.H., Lilystrom, C.G., Corujo-Flores, I.., Zerbi, A.J., Aliaume, C., Churchill, T.N. 1994. The South American sailfin armored catfish, *Liposarcus multiradiatus* (Hancock), a new exotic established in Puerto Rican fresh waters. Caribbean Journal of Science 30:90–94.

Burgess, W.E. 1989. An atlas of freshwater and marine catfishes. A preliminary survey of the Siluriformes. TFH Publication, Neptune City, Canada. 325 pp.

Capps, K.A., Flecker, A.S. 2013. Invasive aquarium fish transform ecosystem nutrient dynamics. Proceedings of the Royal Society B: Biological Sciences 280:20131520. https://doi.org/10.1098/rspb.2013.1520

Capps, K.A., Nico, L.G., Mendoza-Carranza, M., Arévalo-Frías, W., Ropicki, A.J., Heilpern, S.A., Rodiles-Hernández, R. 2011. Salinity tolerance of non-native suckermouth armoured catfish (Loricariidae: *Pterygoplichthys*) in south-eastern Mexico: implications for invasion and dispersal. Aquatic Conservation: Marine and Freshwater Ecosystems 21:528–540. https://doi.org/10.1002/aqc.1210

Castillo, N.A.M., Flores, M.M.A., Vázquez, V.Á., García, R.G., Torres, J.G. 2022. Evaluation of the devilfish (P*terygoplichthys* spp.) natural coagulant as a treatment for the removal of turbidity in fish farm wastewater. Water, Air, & Soil Pollution 233:167. https://doi.org/10.1007/s11270-022-05652-3

Chaichana, R., Jongphadungkiet, S. 2012. Assessment of the invasive catfish *Pterygoplichthys pardalis* (Castelnau, 1855) in Thailand: Ecological impacts and biological control alternatives. Tropical Zoology 25:173–182. https://doi.org/10.1080/03946975.2012.738494

Chaichana, R., Pouangcharean, S., Yoonphand, R. 2011. Habitat, abundance and diet of invasive suckermouth armored catfish (Loricariidae *Pterygoplichthys*) in the Nong Yai Canal, East Thailand. Tropical Zoology 24:49–62.

Chavez, J.M., De La Paz, R.M., Manohar, S.K., Pagulayan, R.C., Vi, J.R.C.

2006. New Philippine record of south American sailfin catfishes (Pisces: Loricariidae). Zootaxa 1109:57–68. https://doi.org/10.11646/zootaxa.1109.1.6

Copp, G.H., Bianco, P.G., Bogutskaya, N.G., Eros, T., Falka, I. 2005. To be, or not to be, a non-native freshwater fish? Journal of Applied Ichthyology 21:242–262. https://doi.org/10.1111/j.1439-0426.2005.00690.x

da Cruz, A.L., Pedretti, A.C.E., Fernandes, M.N. 2009. Stereological estimation of the surface area and oxygen diffusing capacity of the respiratory stomach of the air-breathing armored catfish *Pterygoplichthys anisitsi* (Teleostei: Loricariidae). Journal of Morphology 270:601–614. https://doi.org/10.1002/jmor.10708

da Silva, J.C., Reinas, G.C.Z., Agostinho, A. A., Bialetzki, A. 2022. Chronology of invasion and establishment of *Pterygoplichthys ambrosettii* (Holmberg 1893), in the upper Paraná River basin. Journal of Applied Ichthyology 38:434–441. https://doi.org/10.1111/jai.14340

Dalu, T., Wasserman, R.J., Jordaan, M., Froneman, W.P., Weyl, O.L. 2015. An assessment of the effect of rotenone on selected non-target aquatic fauna. PLoS ONE 10:e0142140 https://doi.org/10.1371/journal.pone.0142140

de Fonseka, R., Radampola, K. 2022. Feasibility of using sailfin catfish meal as an alternative to commercial fishmeal in the diets of juvenile guppy (*Poecilia reticulata*). Journal of Fisheries 10:101203–101203. https://doi.org/10.17017/j.fish.344

Devick, W.S. 1991. Patterns of introductions of aquatic organisms into Hawaiian fresh waters. In: New directions in research, management, and conservation of Hawaiian freshwater stream ecosystems. Proceedings of the 1990 symposium on stream biology and fisheries management. State of Hawaii, Department of Land and Natural Resources, Division of Aquatic Resources, Honolulu, pp. 189–213.

Dixit, A., Dixit, S., Goswami, C.S. 2011. Process and plants for wastewater remediation: a review. Scientific Reviews and Chemical Communications 1:71–77.

DoF. 2020. Yearbook of fisheries statistics of Bangladesh, 2019–2020. Fisheries resources survey system (FRSS), Department of Fisheries, Ministry of Fisheries and Livestock, Bangladesh. 141 pp. https://fisheries.portal.gov.bd/sites/default/files/files/fisheries.portal.gov.bd/download/fa8a7744 (Accessed 30 November 2022).

Donaldson, L.A., Cooke, S.J. 2016. The effectiveness of non-native fish eradication techniques in freshwater ecosystems: a systematic review protocol. Environmental Evidence 5:12. https://doi.org/10.1186/s13750-016-0063-x

Douglas, R.H., Collin, S.P., Corrigan, J. 2002. The eyes of suckermouth armoured catfish (Loricariidae, subfamily *Hypostomus*): pupil response, lenticular longitudinal spherical aberration and retinal topography. Journal of Experimental Biology 205:3425–3433. https://doi.org/10.1242/jeb.205.22.3425

Elfidasari, D., Ismi, L.N., Shabira, A.P., Sugoro, I. 2018. The correlation between heavy metal and nutrient content in Plecostomus (*Pterygoplichthys pardalis*) from Ciliwung River in Jakarta. Biosaintifika: Journal of Biology & Biology Education 10:597–604. https://doi.org/10.15294/biosaintifika.v10i3.16248

Elfidasari, D., Wijayanti, F., Muthmainah, H.F. 2020. Habitat characteristic of suckermouth armoured catfish *Pterygoplichthys pardalis* in Ciliwung River, Indonesia. International Journal of Fisheries and Aquatic Studies 8:141–147.

Englund, R.A. 2000. Nonindigenous freshwater and estuarine species introductions and their potential to affect sportfishing in the lower stream and estuarine regions of the south and west shores of Oahu, Hawaii. Final Report. Bishop Museum Technical Report No. 17, Honolulu, Hawaii. http://www.malamamaunalua.org/wp-content/uploads/Englund-et-al-HBS-2000.pdf (Accessed 17 August 2022).

Escalera-Vázquez, L.H., García-López, J.E., Sosa-López, A., Calderón-Cortés, N., Hinojosa-Garro, D. 2019. Impact of the non-native locariid fish *Pterygoplichthys pardalis* in native fish community on a seasonal tropical floodplain in Mexico. Aquatic Ecosystem Health & Management 22:462–472. https://doi.org/10.1080/14634988.2019.1700343

FAO. 1995. Code of conduct for responsible fisheries. Food and Agriculture Organization, Rome, Italy. https://www.fao.org/3/v9878e/V9878E.pdf (Accessed 30 March 2023).

FAO. 2016. The state of world fisheries and aquaculture. Food and Agriculture Organization, Rome, Italy. https://www.fao.org/documents/card/en/c/2c8bcf47-2214-4aeb-95b0-62ddef8a982a/ (Accessed 30 March 2023).

Flecker, A.S. 1992. Fish trophic guilds and the structure of a tropical stream: Weak direct vs. strong indirect effects. Ecology 73:927–940. https://doi.org/10.2307/1940169

Frazer, T.K., Jacoby, C.A., Edwards, M.A., Barry, S.C., Manfrino, C.M. 2012. Coping with the lionfish invasion: can targeted removals yield beneficial effects? Reviews in Fisheries Science 20:185–191. https://doi.org/10.1080/10641262.2012.700655

Gao, Y., Liu, J.Y., Zhang, T.T., Feng, G.M., Zhang, T., Yang, G., Zhuang, P. 2017. Escaped aquacultural species promoted the alien species invasion in the Yangtze River: A case study of sturgeons. Chinese Journal of Ecology 36:1739–1745. http://dx.doi.org/10.13292/j.1000-4890.201706.011

Geetha, A.S., Thatheyus, A.J. 2019. Influence of amazon sailfin catfish, *Pterygoplichthys pardalis* on the chemical characteristics of dairy effluent. Specialty Journal of Architecture and Construction 5:23–32. https://scialert.net/abstract/?doi=ajbs.2019.733.741

Gestring, K B., Shafland, P.L., Stanford, M.S. 2010. Status of the exotic Orinoco sailfin catfish (*Pterygoplichthys multiradiatus*) in Florida. Florida Scientist 73:122–137. https://www.jstor.org/stable/24321554

Gibbs, M., Futral, T., Mallinger, M., Martin, D., Ross, M. 2010. Disturbance of the Florida manatee by an invasive catfish. Southeastern Naturalist 9:635–648. https://doi.org/10.1656/058.009.0401

Gibbs, M.A., Shields, J.H., Lock, D.W., Talmadge, K.M., Farrell, T.M. 2008. Reproduction in an invasive exotic catfish *Pterygoplichthys disjunctivus* in Volusia Blue Spring, Florida, USA. Journal of Fish Biology 73:1562–1572. https://doi.org/10.1111/j.1095-8649.2008.02031.x

Graham, J.B., Baird, T.A. 1982. The transition to air breathing in fishes: I. Environmental effects on the facultative air breathing of *Ancistrus chagresi* and *Hypostomus plecostomus* Loricariidae. Journal of Experimental Biology 96:53–67. https://doi.org/10.1242/jeb.96.1.53

Grier, H. 1980. Plecostomus. Freshwater and Marine Aquarium 3(8):23–26, 85.

Guillén-Sánchez, E.J., Pacheco-Aguilar, R., Lugo-Sánchez, M.E., Scheuren-Acevedo, S.M., Carvallo-Ruiz, M.G., Navarro-García, G., Ramírez-Suarez, J.C. 2015. Partial characterization of loricariid catfish (*Pterygoplichthys disjunctivus*, Weber, 1991). Biotecnia 17:15–21. https://doi.org/10.18633/bt.v17i3.214

Gusakov, V.A., Stolbunov, I.A., Dien, T.D. 2018. Modern distribution of armored catfishes (Siluriformes: Loricariidae) in central Vietnam. Inland Water Biology 11:179–183. https://doi.org/10.1134/S1995082918020050

Hastings, A., Hall, R.J., Taylor, C.M. 2006. A simple approach to optimal control of invasive species. Theoretical Population Biology 70:431–435. https://doi.org/10.1016/j.tpb.2006.05.003

Haubrock, P.J., Bernery, C., Cuthbert, R.N., Liu, C., Kourantidou, M., Leroy, B., Gozlan, R.E. 2022. Knowledge gaps in economic costs of invasive alien fish worldwide. Science of the Total Environment 803:149875. https://doi.org/10.1016/j.scitotenv.2021.149875

Havel, J.E., Kovalenko, K.E., Thomaz, S.M.S. 2015. Aquatic invasive species: challenges for the future. Hydrobiologia 750:147–170. https://doi.org/10.1007/s10750-014-2166-0

Hay, A., Riggins, C.L., Heard, T., Garoutte, C., Rodriguez, Y., Fillipone, F., Perkin, J.S. 2022. Movement and mortality of invasive suckermouth armored catfish during a spearfishing control experiment. Biological Invasions 24:3119–3131. https://doi.org/10.1007/s10530-022-02834-2

Herath, H.M.G.K., Kalutharage, N.K., Cumaranatunga, P.R.T. 2020. Solutions to an alien species invasion from aquarium aquaculture: Isolation and characterization of acid soluble collagen from sailfin catfish, *Pterygoplichthys disjunctivus* (Weber, 1991) in Sri Lanka. Sri Lanka Journal of Aquatic Sciences 25:19–32. http://doi.org/10.4038/sljas.v25i1.7573

Hill, J.E., Sowards, J. 2015. Successful eradication of the non-native Loricariid catfish *Pterygoplichthys disjunctivus* from the Rainbow River, Florida. Management of Biological Invasions 6:311–317, http://dx.doi.org/10.3391/mbi.2015.6.3.11

Hoover, J.J. 2004. Suckermouth catfishes: threats to aquatic ecosystems of the United States? Aquatic Nuisance Species Research Program Bulletin 4(1):1–13.

Hoover, J.J., Murphy, C.E., Killgore, K.J. 2014. Ecological impacts of suckermouth catfishes (Loricariidae) in North America: A conceptual model. Aquatic Nuisance Species Research Program Bulletin 14(1):1–20. https://apps.dtic.mil/dtic/tr/fulltext/u2/a597286.pdf

Hossain, M.Y., Rahman, M.M., Ahmed, Z.F., Ohtomi, J., Islam, A.B.M.S. 2008. First record of the South American sailfin catfish *Pterygoplichthys multiradiatus* in Bangladesh. Journal of Applied Ichthyology 24:718–720. https://doi.org/10.1111/j.1439-0426.2008.01117.x

Hossain, M.Y., Vadas Jr, R.L., Ruiz-Carus, R., Galib, S.M. 2018. Amazon sailfin catfish *Pterygoplichthys pardalis* (Loricariidae) in Bangladesh: A critical review of its invasive threat to native and endemic aquatic species. Fishes 3:14. https://doi.org/10.3390/fishes3010014

Howard, L., van Rees, C.B., Dahlquist, Z., Luikart, G., Hand, B.K. 2022. A review of invasive species reporting apps for citizen science and opportunities for innovation. NeoBiota 71:165- 188. https://doi.org/10.3897/neobiota.71.79597

Hua, K., Cobcroft, J.M., Cole, A., Condon, K., Jerry, D.R., Mangott, A., Praeger, C., Vucko, M.J., Zeng, C., Zenger, K., Strugnell, J.M. 2019. The future of aquatic protein: implications for protein sources in aquaculture diets. One Earth 1:316–329. https://doi.org/10.1016/j.oneear.2019.10.018

Hubbs, C., Lucier, T., Garrett, G.P., Edwards, R.J., Dean, S.M., Marsh, E., Belk, D. 1978. Survival and abundance of introduced fishes near San Antonio, Texas. Texas Journal of Science 30:369–376.

Hubilla, M., Kis, F., Primavera, J. 2007. Janitor fish *Pterygoplichthys disjunctivus* in the Agusan marsh: a threat to freshwater biodiversity. Journal of Environmental Science and Management 10:10–23. http://hdl.handle.net/10862/3519

Hussan, A., Choudhury, T.G., Das, A., Gita, S. 2016. Suckermouth sailfin catfishes: A future threat to aquatic ecosystems of India. Aquaculture Times 2(6):20–22.

Hussan, A., Mandal, R.N., Hoque, F., Sundaray, J.K., Das, A., Chakrabarti, P.P., Adhikari, S., Udit, U.K., Choudhury, G., Pillai, B.R. 2021. Strategies to control invasion of sailfin armoured catfish, *Pterygoplichthys* spp. in wastewater-fed aquaculture bheries of East Kolkata wetland, India with suggestion of a modified barrier based on the biological and behavioural characteristics. International Journal of Aquatic Biology 9:187–199. https://doi.org/10.22034/ijab.v9i3.897

ICES. 2005. ICES code of practice on the introductions and transfers of marine organisms. International Council for the Exploration of the Seas, Copenhagen, Denmark. https://www.nobanis.org/globalassets/ices-code-of-practice.pdf (Accessed 22 August 2022).

Indarsih, B., Asnawi, A., Purnamasari, D.K. 2016. Sapu-sapu fish (*Hyposarcus pardalis*) as a single protein source for laying mojosari ducks. Journal of Indonesian Tropical Animal Agriculture 41:117–124. https://doi.org/10.14710/jitaa.41.3.117-124

Inger, F.R., Chin, P.K. 2002. The freshwater fishes of North Borneo. The Quarterly Review of Biology 38:204–205. https://doi.org/10.5962/bhl.title.2957

Intawicha. P., Tapingkae, W., Punyatong, M. 2020. Suckermouth armoured catfish (*Pterygoplichthys pardalis*) as a replacement for fish meal in Thai "pradu hang dam" native chicken diets. International Journal of Poultry Science 19:380–384. https://dx.doi.org/10.3923/ijps.2020.380.384

Ishikawa, T., Tachihara, K. 2014. Introduction history of non-native freshwater fish in Okinawa-jima Island: ornamental aquarium fish pose the greatest risk for future invasions. Ichthyological Research 61:17–26. http://dx.doi.org/10.1007/s10228-013-0367-6

IUCN. 2000. IUCN guidelines for the prevention of biodiversity loss caused by alien invasive species. https://portals.iucn.org/library/node/12673 (Accessed 01 April 2023).

IUCN. 2015. Red list of Bangladesh volume 5: freshwater fishes. International Union for Conservation of Nature (IUCN), Bangladesh Country Office, Dhaka, Bangladesh. https://portals.iucn.org/library/node/46327 (Accessed 04 April 2023).

Ju, R.T., Li, X., Jiang, J.J., Wu, J., Liu, J., Strong, D.R., Li, B. 2020. Emerging risks of non-native species escapes from aquaculture: call for policy improvements in China and other developing countries. Journal of Applied Ecology 57:85–90. https://doi.org/10.1111/1365-2664.13521

Jugantar. 2022. Occurrence of suckermouth catfish in the Halda River. https://www.jugantor.com/todays-paper/city/537309 (Accessed 16 March 2022).

Jumawan, J.C., Vallejo, B.M., Herrera, A.A., Buerano, C.C., Fontanilla, I.K.C. 2011. DNA barcodes of the suckermouth sailfin catfish *Pterygoplichthys* (Siluriformes: Loricariidae) in the Marikina River system, Philippines: Molecular perspective of an invasive alien fish species. Philippine Science Letters 4:103–113.

Karthiga, D., Appasamy, S., Antony, J.T. 2019. Biotreatment of sugar industry effluent using the tank cleaner, *Pterygoplichthys pardalis*. World Journal of Advanced Research and Reviews 1:14–27. https://doi.org/10.30574/wjarr.2019.1.3.0015

Krishnakumar, K., Raghavan, R., Prasad, G., Bijukumar, A., Sekharan, M., Pereira, B., Ali, A. 2009. When pets become pests-exotic aquarium fishes and biological invasions in Kerala, India. Current Science 97:474–476. http://www.jstor.org/stable/24111872.

Kumar, M.S., Thatheyus, A.J., Ramya, D. 2016. Biotreatment of sewage using the amazon sailfin catfish, *Pterygoplichthys pardalis*. Academic Journal of Life Sciences 2:41–49. https://ideas.repec.org/a/arp/ajlsar/2016p41-49.html

Leung, B., Roura-Pascual, N., Bacher, S., Heikkilä, J., Brotons, L., Burgman, M.A., Vilà, M. 2012. TEASIng apart alien species risk assessments: a framework for best practices. Ecology Letters 15:1475–1493. https://doi.org/10.1111/ele.12003

Liang, S.H., Wu, H.P., Shieh, B.S. 2005. Size structure, reproductive phenology, and sex ratio of an exotic armoured catfish (*Liposarcus multiradiatus*) in the Kaoping River of southern Taiwan. Zoological

Studies-Taipei 44:252–259.
MacCormack, T.J., Treberg, J.R., Almeida-Val, V.M., Val, A.L., Driedzic, W.R. 2003. Mitochondrial KATP channels and sarcoplasmic reticulum influence cardiac force development under anoxia in the Amazonian armored catfish *Liposarcus pardalis*. Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology 134:441–448. https://doi.org/10.1016/S1095-6433(02)00315-X
Mack, R.N., Simberloff, D., Mark Lonsdale, W., Evans, H., Clout, M., Bazzaz, F.A. 2000. Biotic invasions: causes, epidemiology, global consequences, and control. Ecological Applications 10:689–710. https://doi.org/10.1890/1051-0761(2000)010%5b0689:BICEGC%5d2.0.CO;2
Mamun, S.A.A., Hossain, M.S., Capps, K.A. 2023. Promoting community-based surveillance of economically important invasive species in lower-income economies: A case study of the suckermouth catfish (*Pterygoplichthys pardalis*) in Bangladesh. Biological Invasions 25:1285–1290. https://doi.org/10.1007/s10530-022-02993-2
Manfrin, C., Souty-Grosset, C., Anastácio, P.M., Reynolds, J., Giulianini, P.G. 2019. Detection and control of invasive freshwater crayfish: from traditional to innovative methods. Diversity 11:5. https://doi.org/10.3390/d11010005
Marchetti, M.P., Moyle, P.B., Levine, R. 2004. Invasive species profiling? Exploring the characteristics of non-native fishes across invasion stages in California. Freshwater Biology 49:646–661. https://doi.org/10.1111/j.1365-2427.2004.01202.x
Mazzoni, R., Caramaschi, E.P. 1997. Spawning season, ovarian development and fecundity of *Hypostomus affinis* (Osteichthyes, Loricariidae). Revista Brasileira de Biologia 57:455–462.
Meena, M., Sundaramanickam, A., Kumar, T.T.A. 2016. Occurrence of a *Pterygoplichthys disjunctivus* (Weber, 1991) population in Cauvery River system, Tamil Nadu, South India. International Journal of Fisheries and Aquaculture 8:62–66. https://doi.org/10.5897/IJFA2015.0526
Mendoza, R.E., Cudmore, B., Orr, R., Balderas, S.C., Courtenay, W.R., Osorio, P.K., Mandrak, N., Torres, P.A., Damián, M.A., Gallardo, C.E., Sanguinés, A.G., Greene, G., Lee, D., Orbe-Mendoza, A., Martínez, C.R., Arana, O.S. 2009. Trinational risk assessment guidelines for aquatic alien invasive species. Commission for Environmental Cooperation, Montréal (Québec), Canada. 92 pp.
Mendoza-Alfaro, R., Fisher, J. P., Courtenay, W., Ramírez-Martínez, C., Escalera, C., Torres, P. A., Osorio, P. K., Contreras-Balderas, S. 2009. Armored catfish (Loricariidae) trinational risk assessment. In: Trinational risk assessment guidelines for alien invasive species. Commission for Environmental Cooperation, Montréal (Québec), Canada, pp. 25–37.
Mendoza-Alfaro, R., Ramírez-Martínez, C., Contreras-Balderas, S., Koleff-Osorio, P., Álvarez-Torres, P. 2010. Aquarium trade as a pathway for the introduction of invasive species into Mexico. In: Freshwater ecosystems and aquaculture research, Carlo, F. D., Bassano, S. (Eds.), Nova Publishers, Hauppauge, New York, pp. 209–224.
Mengumphan, K., Saengkrachang, J. 2008. Production of generation-2 Mekong giant catfish (*Pangasinodon gigas*) cultured with *Spirulina* sp. Maejo International Journal of Science and Technology 2:559–567.
Millamena, O.M. 2002. Replacement of fish meal by animal by-product meals in a practical diet for grow-out culture of grouper *Epinephelus coioides*. Aquaculture 204:75–84. https://doi.org/10.1016/S0044-8486(01)00629-9
MoFL. 2023. Bangladesh gazette (SRO-6). Ministry of Fisheries and Livestock, Bangladesh. https://www.dpp.gov.bd/bgpress/index.php/document/get_extraordinary/47502 (Accessed 10 February 2023).
Mogalekar, H. S., Jawahar, P., Srinivasan, A., Marx, K. K., Sujathkumar, N. V., Canciyal, J., Sudhan, C. 2017. Discovery of the Amazon sailfin catfish *Pterygoplichthys pardalis* (Castelnau, 1855) (Teleostei: Loricariidae) from Manimuthar dam, Tamiraparani River system, India. Journal of Entomology and Zoology Studies 5:1229–1231.
Mohanty, B. P., Ganguly, S., Mahanty, A., Mitra, T., Mahaver, L., Bhowmick, S., Das, B. K. 2017. Nutritional composition of the invasive *Pterygoplichthys disjunctivus* from East Kolkata Wetland, India. Journal of the Inland Fisheries Society of India 49:48–54.
Moyle, P.B. 2002. Inland fishes of California: revised and expanded. University of California Press, Los Angeles. 489 pp.
Moyle, P.B., Light, T. 1996. Biological invasions of fresh water: Empirical rules and assembly theory. Biological Conservation 78:149–161. https://doi.org/10.1016/0006-3207(96)00024-9
N'Guyen, A., Hirsch, P. E., Adrian-Kalchhauser, I., Burkhardt-Holm, P. 2016. Improving invasive species management by integrating priorities and contributions of scientists and decision makers. Ambio 45:280–289. https://doi.org/10.1007/s13280-015-0723-z
Naylor, R.L., Williams, S.L., Strong, D.R. 2001. Aquaculture–A gateway for exotic species. Science 294:1655–1656. https://doi.org/10.1126/science.1064875
Newagebd. 2020. Alien fish threatens Bangladesh aquatic ecology. https://www.newagebd.net/article/122634/alien-fish-threatens-bangladesh (Accessed 27 February 2022).
Newagebd. 2021. Commercial production of suckermouth catfish in Bangladesh causes concern https://www.newagebd.net/article/135124/commercial-production-of-suckermouth-catfish-in-bangladesh-causes-concern (Accessed 17 June 2022).
Nico, L. 2000. *Pterygoplichthys multiradiatus* (Hancock 1828). Nonindigenous aquatic species fact sheet 768. United States Geological Survey. https://nas.er.usgs.gov/queries/FactSheet.aspx?speciesID=768 (Accessed 02 June 2022).
Nico, L.G., Butt, P.L., Johnston, G.R., Jelks, H.L., Kail, M., Walsh, S.J. 2012. Discovery of South American suckermouth armored catfishes (Loricariidae, *Pterygoplichthys* spp.) in the Santa Fe River drainage, Suwannee River basin, USA. BioInvasions Record 1:179–200. https://doi.org/10.3391/bir.2012.1.3.04
Nico, L.G., Jelks, H.L., Tuten, T. 2009. Non-native suckermouth armored catfishes in Florida: Description of nest borrows and burrow colonies with assessment of shoreline conditions. Aquatic Nuisance Species Research Program Bulletin 9:1–30.
Nico, L.G., Martin, R.T. 2001. The South American suckermouth armored catfish, *Pterygoplichthys anisitsi* (Pisces: Loricaridae), in Texas, with comments on foreign fish introductions in the American Southwest. The Southwestern Naturalist 46:98–104. https://doi.org/10.2307/3672381
Nitta, M., Nagasawa, K. 2013. First Japanese record of *Heteropriapulus heterotylus* (Monogenea: Dactylogyridae), from the alien catfish *Pterygoplichthys disjunctivus* (Siluriformes: Loricariidae) in Okinawa. Species Diversity 18:281–284. https://doi.org/10.12782/sd.18.2.281
Orfinger, A.B., Goodding, D.D. 2018. The global invasion of the suckermouth armored catfish genus *Pterygoplichthys* (Siluriformes: Loricariidae): Annotated list of species, distributional summary, and assessment of impacts. Zoological Studies 57:7. https://doi.org/10.6620/ZS.2018.57-07
Özdilek, Ş.Y. 2007. Possible threat for Middle East inland water: an exotic and invasive species, *Pterygoplichthys disjunctivus* (Weber, 1991) in Asi River, Turkey (Pisces: Loricariidae). Ege Journal of Fisheries and Aquatic Sciences 24:303–306. http://www.egejfas.org/en/pub/issue/5011/67843
Page, L.M. 1994. Identification of sailfin catfishes introduced to Florida.

Florida Scientist 57(4):171–172.

Page, L.M., Burr, B.M. 1991. A field guide to freshwater fishes: North America, north of Mexico. Houghton Mifflin Company, Boston. 432 pp. https://doi.org/10.1007/bf00045047

Page, L.M., Robins, R.H. 2006. Identification of sailfin catfishes (Teleostei: Loricariidae) in southeastern Asia. The Raffles Bulletin of Zoology 54:455–457.

Panase, P., Uppapong, S., Tuncharoen, S., Tanitson, J., Soontornprasit, K., Intawicha, P. 2018. Partial replacement of commercial fish meal with Amazon sailfin catfish *Pterygoplichthys pardalis* meal in diets for juvenile Mekong giant catfish *Pangasianodon gigas*. Aquaculture Reports 12:25–29. https://doi.org/10.1016/j.aqrep.2018.08.005

Phillips, M.J., Fisher, J.P., Saidin, T., Subasinghe, R.P., Ponniah, A.G. 2004. Building capacity to combat impacts of aquatic invasive alien species and associated transboundary pathogens in ASEAN countries. FAO Aquaculture Newsletter 32:33–36. https://www.fao.org/3/y5878e/y5878e10.pdf

Podder, M., Islam, M.S., Bhuyan M.S. 2017. Inventory of watershed area of the Halda River basin for ecosystem health management. Research Journal of Environmental Sciences 11:170–176. https://dx.doi.org/10.3923/rjes.2017.170.176

Pound, K.L., Nowlin, W.H., Huffman, D.G., Bonner, T.H. 2011. Trophic ecology of a nonnative population of suckermouth catfish (*Hypostomus plecostomus*) in a central Texas spring-fed stream. Environmental Biology of Fishes 90:277–285. https://doi.org/10.1007/s10641-010-9741-7

Power, M.E. 1984. Depth distributions of armored catfish: predator-induced resource avoidance? Ecology 65:523–528. https://doi.org/10.2307/1941414

Puspitasari, R.L., Alwan, M., Khavidhar, F., Gustiananda, K.A., Widyanto, P.C.A., Anisah, S., Haq, A. 2021. Bone flour from suckermouth fish (*Pterygoplichthys*) and tilapia fish (*Oreochromis mossambicus*). International Journal of Bioscience and Biotechnology 9:42–48. https://doi.org/10.24843/IJBB.2021.v09.i01.p05

Qasim, A.M., Jawad, L.A. 2022. Presence of the Amazon sailfin catfish, *Pterygoplichthys pardalis* (Castelnau, 1855) (Pisces: Loricariidae), in the Shatt al-Arab River, Basrah, Iraq. Integrative Systematics: Stuttgart Contributions to Natural History 5:95–103. https://doi.org/10.18476/2022.647187

Rahman, M.M., Bashar, M.A., Farhana, Z., Hossain, M.Y. 2014. Temporal variation of physicochemical parameters in Kaptai Lake, Bangladesh. World Journal of Fish and Marine Sciences 6:475–478.

Raj, S., Kumar, A.B., Raghavan, R., Dahanukar, N. 2020. Amazonian invaders in an Asian biodiversity hotspot: Understanding demographics for the management of the armoured sailfin catfish, *Pterygoplichthys pardalis* in Kerala, India. Journal of Fish Biology 96:549–553. https://doi.org/10.1111/jfb.14243

Rao, K.R., Sunchu, V. 2017. A report on *Pterygoplichthys pardalis* Amazon sailfin suckermouth catfishes in freshwater tanks at Telangana state, India. International Journal of Fisheries and Aquatic Studies 5:249–254.

Robertson, P.A., Mill, A., Novoa, A., Jeschke, J.M., Essl, F. 2020. A proposed unified framework to describe the management of biological invasions. Biological Invasions 22:2633–2645. https://doi.org/10.1007/s10530-020-02298-2

Roxo, F.F., Ochoa, L.E., Sabaj, M.H., Lujan, N.K., Covain, R., Silva, G.S., Melo, B.F., Albert, J.S., Chang, J., Foresti, F., Alfaro, M.E., Oliveira, C. 2019. Phylogenomic reappraisal of the Neotropical catfish family Loricariidae (Teleostei: Siluriformes) using ultraconserved elements. Molecular Phylogenetics and Evolution 135:148–165. https://doi.org/10.1016/j.ympev.2019.02.017

Rubio, V.Y., Gibbs, M.A., Work, K.A., Bryan, C.E. 2016. Abundant feces from an exotic armored catfish, *Pterygoplichthys disjunctivus* (Weber, 1991), create nutrient hotspots and promote algal growth in a Florida spring. Aquatic Invasions 11:337–350. http://dx.doi.org/10.3391/ai.2016.11.3.11

Rueda-Jasso, R.A., Campos-Mendoza, A., Arreguín-Sánchez, F., Díaz-Pardo, E., Martínez-Palacios, C.A. 2013. The biological and reproductive parameters of the invasive armoured catfish *Pterygoplichthys disjunctivus* from Adolfo López Mateos El Infiernillo Reservoir, Michoacán-Guerrero, Mexico. Revista Mexicana De Biodiversidad 84:318–326. https://doi.org/10.7550/rmb.26091

Saba, A.O., Rasli, N.F., Ismail, A., Zulkifli, S.Z., Ghani, I.F.A., Muhammad-Rasul, A.H., Azmai Amal, M.N. 2020. A report on introduced amazon sailfin catfish, *Pterygoplichthys pardalis* in Gombak Basin, Selangor, with notes on two body patterns of the species. Pertanika Journal of Tropical Agricultural Science 43:693–703. https://doi.org/10.47836/pjtas.43.4.19

Saimon, M.K., Mustafa, M.G., Sarker, B.S., Hossain, M.B., Rahman, M.M. 2016. Marketing channels of Indian carp fry collected from Halda River and livelihood of the fry traders. Asian Research Journal of Agriculture 10:28–37. https://doi.org/10.3923/ajar.2016.28.37

Scott, S.E., Pray, C.L., Nowlin, W.H., Zhang, Y. 2012. Effects of native and invasive species on stream ecosystem functioning. Aquatic Sciences 74:793–808. https://doi.org/10.1007/s00027-012-0263-6

Seaman, A.N., Franzidis, A., Samuelson, H., Ivy, S. 2022. Eating invasives: chefs as an avenue to control through consumption. Food, Culture & Society 25:108–125. https://doi.org/10.1080/15528014.2021.1884423

Seshagiri, B., Swain, S.K., Pillai, B.R., Satyavati, C., Sravanti, Y., Rangacharyulu, P.V., Ratnaprakash, V. 2021. Suckermouth armoured catfish (*Pterygoplichthys* spp.) menace in freshwater aquaculture and natural aquatic systems in Andhra Pradesh, India. International Journal of Fisheries and Aquatic Studies 9:375–384. https://doi.org/10.22271/fish.2021.v9.i1e.2423

Stolbunov, I.A., Dien T.D., Karabanov, D.P. 2021. Taxonomic composition and distribution of alien suckermouth armored catfish (Siluriformes: Loricariidae) in Southern Vietnam. Inland Water Biology 14:263–273. https://doi.org/10.1134/S1995082921030123

Sumanasinghe, H.W., Amarasinghe, U. S. 2014. Population dynamics of accidentally introduced Amazon sailfin catfish, *Pterygoplichthys pardalis* (Siluriformes, Loricariidae) in Pologolla reservoir, Sri Lanka. Sri Lanka Journal of Aquatic Sciences 18:37–45. http://dx.doi.org/10.4038/sljas.v18i0.7040

Suresh, V.R., Ekka, A., Biswas, D.K., Sahu, S.K., Yousuf, A., Das,S. 2019. Vermiculated sailfin catfish, *Pterygoplichthys disjunctivus* (Actinopterygii: Siluriformes: Loricariidae): invasion, biology, and initial impacts in east Kolkata Wetlands, India. Acta Ichthyologica Et Piscatoria 49:221–233. https://doi.org/10.3750/AIEP/02551

Thorvaldsen, T., Holmen, I.M., Moe, H.K. 2015. The escape of fish from Norwegian fish farms: Causes, risks and influence of organisational aspects. Marine Policy 55:33–38. https://doi.org/10.1016/j.marpol.2015.01.008

Tisasari, M., Efizon, D., Pulungan, C.P. 2016. Stomach content analysis of *Pterygoplichthys pardalis* from the Air Hitam River, Payung Sekaki district, Riau province." Jurnal Online Mahasiswa Fakultas Perikanan dan Ilmu Kelautan Universitas Riau 3:1–14. (in Indonesian). https://jom.unri.ac.id/index.php/JOMFAPERIKA/article/view/8927

Varble, S., Secchi, S. 2013. Human consumption as an invasive species management strategy. A preliminary assessment of the marketing potential of invasive Asian carp in the US. Appetite 65:58-67. https://doi.org/10.1016/j.appet.2013.01.022

Veena, V., Sasikala, G., Raja, S. 2023. Occurrence of South American sucker armoured catfish (*Pterygoplichthys pardalis*) in the Gayathripuzha River, Palakkad, Kerala. International Journal of Fisheries and Aquatic Studies 11:08–17. https://doi.org/10.22271/fish.2023.v11.i2a.2783

Vitule, J.R.S., Freire, C.A., Simberloff, D. 2009. Introduction of nonnative freshwater fish can certainly be bad. Fish and Fisheries 10:98–108. https://doi.org/10.1111/j.1467-2979.2008.00312.x

Walker, B. 1968. The fish with the folded mouth. Aquarium Series II 1:36–43.

Weber, C. 1992. Révision du genre *Pterygoplichthys sensu* lato (Pisces, Siluriformes, Loricariidae). Revue Française D'aquariologie 19:1–36.

Wei, H., Copp, G.H., Vilizzi, L., Liu, F., Gu, D., Luo, D., Xu, M., Mu, X., Hu, Y. 2017. The distribution, establishment and life-history traits of non-native sailfin catfishes *Pterygoplichthys* spp. in the Guangdong Province of China. Aquatic Invasions 12:241–249. https://doi.org/10.3391/ai.2017.12.2.11

Wei, H., Hu, Y., Li, S., Chen, F., Luo, D., Gu, D., Yang, Y. 2019. A review of freshwater fish introductions to the Guangdong province, China. Aquatic Ecosystem Health & Management 22:396–407. https://doi.org/10.1080/14634988.2019.1685850

Wei, H., Liu, F., Vilizzi, L., Wood, L. E., Hu, Y., Copp, G. H. 2022. Environmental related variation in growth and life-history traits of non-native sailfin catfishes (*Pterygoplichthys* spp.) across river basins of South China. Aquatic Invasions 17:92–109. https://doi.org/10.3391/ai.2022.17.1.06

Werner, D. 1982. Review of man, fishes, and the amazon. Human Ecology 10:151–153. http://www.jstor.org/stable/4602640

Wijesinghe, S.K.D., Abeyrathne, E.D.N.S., Vidanarachchi, J.K., Rajapakse, R.P.N.P. 2021. Bioactive properties of fish protein hydrolysates from Amazon sailfin catfish (*Pterygoplichthys pardalis*) from the Victoria Reservoir in Sri Lanka. Tropical Agricultural Research 32:219–228. http://doi.org/10.4038/tar.v32i2.8469

Winemiller, K.O. 1989. Patterns of variation in life history among South American fishes in seasonal environments. Oecologia 81:225–241. https://doi.org/10.1007/BF00379810

Wu, LW., Liu, C.C., Lin, S.M. 2011. Identification of exotic sailfin catfish species (*Pterygoplichthys*, Loricariidae) in Taiwan based on morphology and mtDNA sequences. Zoological Studies 50:235–246.