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Upcycling Approaches of Invasive Suckermouth Catfish as a Control Strategy: Translating Global Practices to Bangladesh

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Abstract

The suckermouth catfish (SMC, family Loricariidae), native to South America, has become a globally invasive species, now documented in 22 countries across tropical, subtropical, and warm-water regions. Like many invasive species, SMCs adversely impact local ecosystems and biodiversity. Recent reports of their proliferation in Bangladesh's inland waters have raised significant ecological concerns, prompting the government to impose a nationwide ban on SMCs in 2022. However, comprehensive control measures will not be effective and efficient without upcycling practices. Thus, utilising data from scientific databases, this study summarises potential upcycling techniques for SMC. Fish meal and bone flour, products for animal consumption, were identified in the literature as nutritious alternative feed additives derived from SMC. Laboratory production of value-added items, such as collagen, alkaline protease, gelatine, and protein hydrolysate, was conducted at a minimal scale using SMC. Suckermouth catfish utilisation for human nutrition, biofuel production, fertiliser development, and cultural applications (e.g., souvenirs or gifts) suggests its strong potential for implementing a circular economy. Only a limited number of studies have explored its potential in sewage biotreatment or medicinal applications, such as bone healing. However, to date, very limited research on the SMC upcycling methods has been conducted in Bangladesh. Heavy metal concentration is a matter of concern for SMC upcycling. This study identifies critical research gaps and challenges that should be addressed to implement the concepts of upcycling.

Keywords: *Pterygoplichthys*, *Hypostomus*, distribution, utilisation, fish products

Introduction

Suckermouth catfish (SMC, family Loricariidae) came from South America (Froese and Pauly, 2013; Nico and Neilson, 2013; Page et al., 2013; Nico et al., 2019) and invaded many tropical, sub-tropical, and warm waters throughout the world (Villalba-Villalba et al., 2011; Ramlan et al., 2023). The SMC has spread to 22 countries in the Americas, Asia, Africa, and Europe (Maddern, 2015; Orfinger and Douglas Goodding, 2018). The suckermouth family of catfishes is the largest in the world, with over 550 species (Hoover et al., 2014). Unintentional and ignorant, or purposeful and neglected escape from the aquaria, introduced SMCs into local freshwater bodies such as rivers, ponds, and lakes (Landau, 2019; Saba et al., 2020) with native fishes.

Suckermouth catfish, belonging to the family Loricariidae, genus *Pterygoplichthys*, and *Hypostomus*, thrives in low-lying areas with reduced oxygen levels (Barletta et al., 2000; Chaichana and Jongphadungkiet, 2012; Hoover et al., 2014). They can adapt to a spectrum of water conditions, including polluted conditions (Chavez, de La Paz et al., 2006), and exhibit salt tolerance (CEC, 2009; Maddern, 2015). Reports from various countries revealed that SMC had a notable impact on aquatic organisms, mainly native fish, by altering habitats and influencing biodiversity (Radkhah and Eagderi, 2020). They also act as egg predators and carriers for non-native parasites (Chaichana and Jongphadungkiet, 2012; Rodríguez-Santiago et al., 2016). Additionally, aquaculture incurs losses due to SMC feeding on benthic algae and debris, which alters the food chain (Hussan et al., 2016), and consuming a large portion of the feed intended for the culture species. The SMC has anti-predatory adaptations, such as bony armoured plates and dorsal and pectoral spines (Faridah-Hanum and Latiff, 2021), that deter predators and there is a lack of native predators for SMCs (Ramlan et al., 2023). These extreme adaptive and predatory features of SMC facilitated the invasion in Bangladesh, causing damage to the ecology, biodiversity, and aquaculture.

The suckermouth catfish species were introduced into Bangladesh during the 1980s as a pet due to its attractive appearance and cleaning behaviour (Hoover et al., 2004) and was first found in the lakes of Gulshan and Banani in the mid-1990s. Subsequent media accounts suggest that the catfish likely spread to the Shitalakkhya River in Narayanganj around the same time (Hossain, 2020). Currently, SMC has become established as an invasive species in Bangladesh, a process that is estimated to require five to ten years (Sarkar et al., 2023), which is consistent with the results of the climate matching analysis (USFWS, 2018). As a result of recent worrying occurrences in local water bodies and the threat posed by SMC, Bangladesh banned the fish in 2022 under the Protection and Conservation of Fish Rules, 1985 (Sarkar et al., 2023). Following the ban, Bangladesh Fisheries Research Institute conducted awareness campaigns and destroyed breeding grounds (Sarkar et al., 2023). Controlling the SMC population is a major concern for open-water fisheries and aquaculture in Bangladesh.

However, the lack of established control methods could complicate management and challenge aquaculture (Nico and Martin, 2001; Hoover et al., 2014; Sarkar et al., 2023). Researchers have suggested control strategies like physical removal, encouraging consumption, and increasing public awareness (Hossain et al., 2018; Orfinger and Douglas Goodding, 2018). Moreover, spearfishing reduced biomass but did not completely eradicate the population (Hay et al., 2022). So, for the intended outcome, it is necessary to eliminate SMC from natural water sources and simultaneously benefit from its presence (Panase et al., 2018). Additionally, when control measures are implemented, alien invasive fish like SMC will be discarded as waste due to a lack of demand (Sarkar et al., 2023). As a result, the implementation of controlling approaches will be challenging and expensive. Also, fishermen may perceive the capture of SMC as a burden if it is not utilised appropriately. Hence, in promoting sustainable aquaculture and facilitating long-term control measures through increased consumption and reduced SMCs from natural waters, no feasible alternative is available to the "upcycling" of SMCs.

Upcycling refers to making valuable products using waste materials (Sung et al., 2014). Creation of a (Hoover et al., 2014) valuable product from an underutilised or waste is the principle of upcycling (Oxford University Press, 2024). Thus, various measures for upcycling might help control the SMC stock by ensuring proper utilisation of the fish. The word "Upcycle" is also used to suggest reducing the invasive fish population, as the prime objective of the utilisation of SMC, not to promote profitable SMC culture (Varble and Secchi, 2013).

Since the invasion has already spread to multiple regions across the world, studies on various methods of utilising these fish have been initiated as part of control strategies (Ramlan et al., 2023). Nonetheless, research on SMC utilisation remains severely limited in Bangladesh. Therefore, this review was undertaken to consolidate and synthesise existing information to assess potential upcycling options for SMC worldwide as an output-oriented control mechanism for invasive populations and to provide insight for Bangladeshi researchers, innovators, and policymakers.

Materials and Methods

This review focuses specifically on exploring potential upcycling processes for both conventional and non-conventional products derived from SMC. A systematic search of scholarly literature was conducted using the Google Scholar, Scopus and Web of Science (WOS) databases, targeting publications available in English and encompassing the title, abstract, and keywords fields (TITLE-ABS-KEY). The primary search term employed was "Sucker Mouth Catfish," combined with various pertinent keywords, including "*Hypostomus*," "*Pterygoplichthys*," "distribution in Bangladesh," "proximate composition," "fish products," "fish meal," "value-added products," "wastewater treatment," "medical use," and "heavy metal."

Following the retrieval of papers from scientific databases, duplicate papers were eliminated. Subsequently, a preliminary screening process was conducted based on a careful examination of titles and abstracts to exclude articles with little relevance to the topic. The exclusion criteria employed were as follows:

- Studies focusing on the distribution of fish species other than SMCs were excluded.
- Articles solely addressing fish products not intended for SMCs were omitted.
- Studies that discussed scientifically evaluated or industrially practiced products were considered.

Around 100 selected articles were utilised to compile summary tables, maps, and figures elucidating findings related to SMC distribution and potential upcycling methods, along with associated challenges and recommendations pertaining to prospects in Bangladesh.

Distribution of Suckermouth Catfish

Suckermouth catfish (SMC) have been widely introduced across tropical and subtropical regions (Fig. 1) due to their unique appearance, environmental tolerance, and cleaning ability (Hoover et al., 2004). In Bangladesh, SMCs are known to be a popular ornamental fish. Nevertheless, in the last decade, mainly in the last five years, various species of SMCs have been found in natural waters throughout the country (Fig. 1).

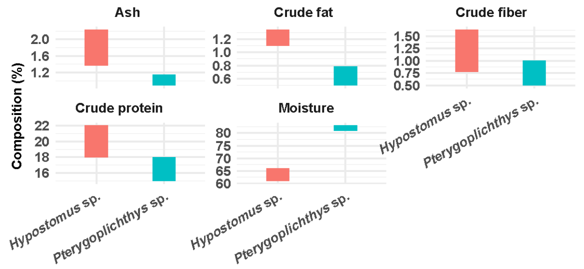

Fig. 2. The nutritional composition of major suckermouth (SMC) genera (live weight basis) (Asnawi et al., 2015; Ariyarathne et al., 2016; Mohanty et al., 2017; Hasrianti et al., 2022).

Proximate Composition of Suckermouth Catfish

Possessing significant nutritional benefits, the SMC fish serves as a valuable reservoir of carbohydrates, protein, and omega-6 fatty acids, as identified by Mengumphan and Saengkrachang (2008). Nations grappling with the impact of this invasive species have conducted studies involving proximate analysis of these fish (Fig. 2) and have devised technologies for processing, transforming this challenge into an opportunity within the fisheries sector.

Scopes of Upcycling of Suckermouth Catfish

From previous studies, we know that SMCs can be upcycled in different ways to render traditional and nontraditional products or services. The conversion of SMCs from valueless biological waste to a value-added product can be achieved by implementing the following processes.

Animal feed additives

Fish meal

The use of *P. pardalis* to produce commercial fish feed (Sumanasinghe and Amarasinghe, 2014; Abesinghe et al., 2020) can be a way to reduce the size of SMC populations in natural waters (Panase et al., 2018). The high protein, omega-6 fatty acid, and good nutritional quality of SMC (Mengumphan and Saengkrachang, 2008) make it a suitable candidate for commercial feed production. Scientists found *Pterygoplichthys* sp. could effectively replace fish meal up to 100 % as a feed for *Pangasianodon gigas* (Panase et al., 2018) and *Oreochromis niloticus* (Cano-Salgado et al., 2022).

According to these studies, complete replacement of fish meal by SMC meal had no discernible effect on the fish's growth, digestibility, or feed utilisation (Millamena, 2002; Panase et al., 2018; Cano-Salgado et al., 2022). Also, given the limited availability of raw materials in industrial processes, an alternative

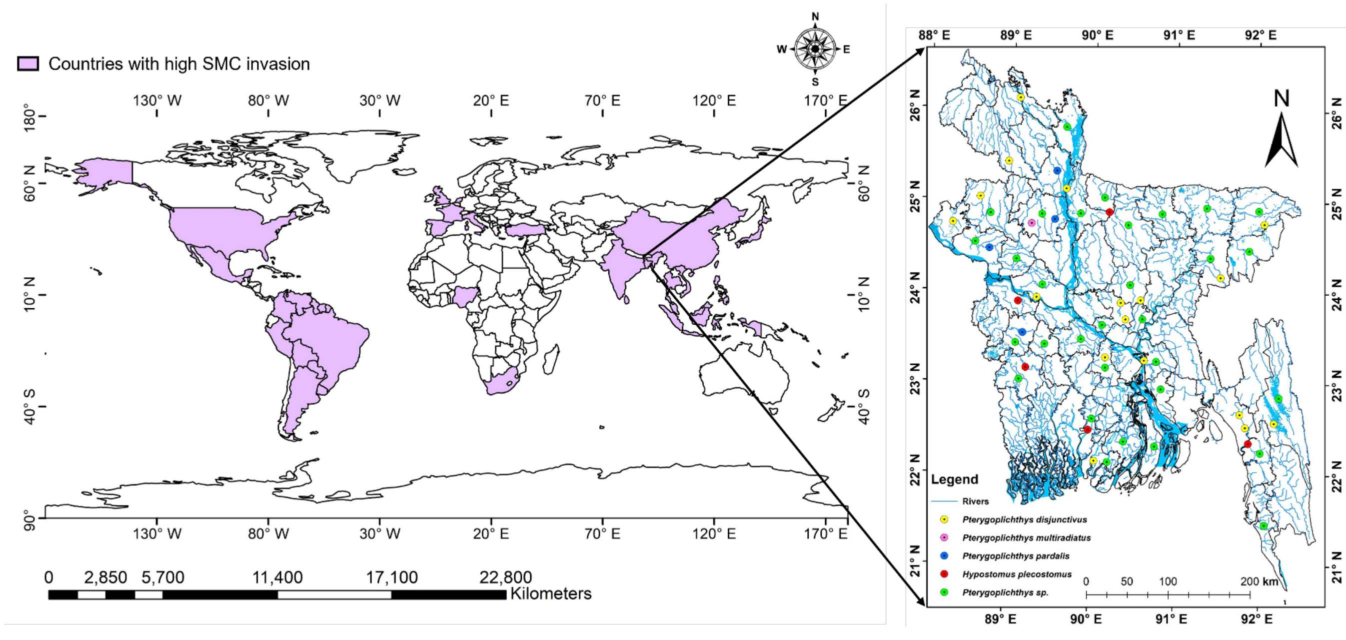

Fig. 1. Geographic range of suckermouth catfishes (Family: Loricariidae), including Bangladesh (Hossain et al., 2008, 2018; Galib et al., 2013; Nico and Neilson, 2013; Hoover et al., 2014; Maddern, 2015; Prothom Alo English, 2017; Bashar et al., 2020; Kabir and Hawkeswood, 2021; Shefat, 2021; Islam, 2023; Mamun et al., 2023; Parvez et al., 2023).

strategy could involve investigating the feasibility of using SMC as a supplementary resource for production (Islam et al., 2021)(Fig. 3). Bangladesh's Chittagong and Mymensingh have two industries that produce fish meal and fish oil from fish silage. Since raw materials are scarce in these factories, they can utilise SMC (Islam et al., 2021). This approach could offer Bangladesh a dual solution by addressing invasive species control while simultaneously supplementing protein-rich feed ingredients.

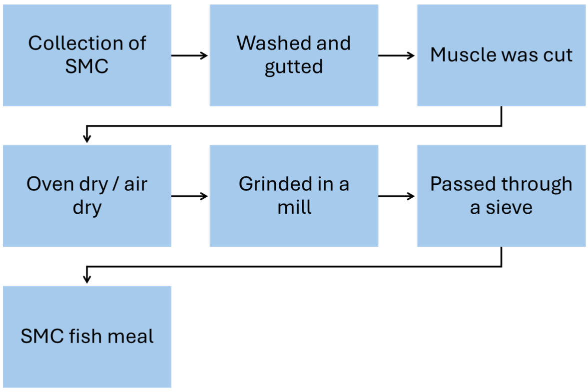

Fig. 3. Process of producing fish meal using suckermouth catfish (SMC) (modified from Panase et al., 2018; Cano-Salgado et al., 2021).

Bone flour

Protein rich bone flour can be prepared from SMCs, especially *Pterygoplichthys pardalis* (Fig.4). This product can be used in food technology and play a vital role in biodiversity conservation (Puspitasari et al., 2021). Unlike conventional meat-and-bone meal (MBM) which is linked to bovine spongiform encephalopathy (BSE) risks through pathogenic prion transmission (Islam et al., 2022), SMC-based bone flour offers a safe alternative ingredient that aligns with existing commercial production infrastructure of bone meal in Bangladesh (Barman et al., 2020). This presents a unique opportunity to adapt international best practices for local invasive species management while addressing food safety concerns in the aquaculture feed industry.

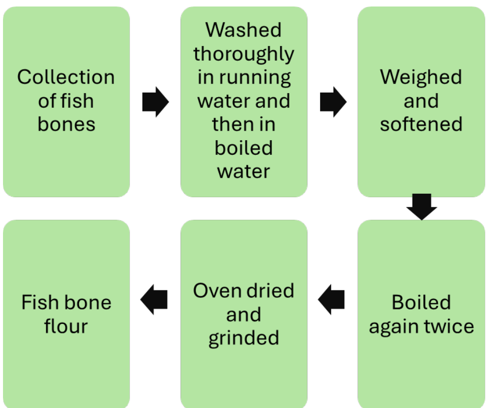

Fig. 4. Process of bone flour preparation from suckermouth catfish SMC (modified from Puspitasari et al., 2021).

Value added products

Enhancing value and diversifying fish products contribute significantly to meeting the dynamic and varied demands of fish products for consumers. Several byproducts and value-added products derived from SMC have been documented (Ariyarathne et al., 2016; Herath et al., 2020; Puspitasari et al., 2021; Wijesinghe et al., 2021) worldwide. Therefore, producing such products can be a management alternative in Bangladesh, considering the safety and acceptance of people (Sarkar et al., 2023).

Fish protein hydrolysate (FPH)

Hydrolysis of fish proteins is one of the effective measures to produce bioactive and functional feed ingredients. Suckermouth catfishes, an invasive fish and underutilised by-catch, can be used to produce value added products like protein hydrolysates (Ramírez-Ramírez et al., 2008). Wijesinghe et al. (2021) mentioned that *Pterygoplichthys pardalis* can be processed into fish protein hydrolysate (FPH) (Fig. 5), with the resulting FPH exhibiting both antioxidative and antimicrobial properties. In the context of catfish farming in Bangladesh, using FPH derived from SMCs to produce, may hold significant potential as an excellent feed additive. Suma et al. (2023) observed an improved growth performance, health condition, and disease resistance of pabda (*Ompok pabda*) fingerlings in captivity by using 2 % FPH. Moreover, the ability to produce FPH from either fish byproducts or whole fish makes this an effective upcycling strategy (Zamani and Benjakul, 2016; Petrova et al., 2018), particularly advantageous for resource-limited countries such as Bangladesh.

Collagen

Collagen is a fibrous protein that acts as a building block for connective tissues like skin and composes one-quarter of the body's protein. Like enzymes, collagen is also extracted mostly from mammals. Only in the past few years have aquatic organisms gained the interest of scientists as an alternative source of collagen because fish collagen has a qualitative advantage over mammalian collagen. Studies showed that skin (Herath et al., 2020; Ramlan et al., 2023) and flesh (Herath et al., 2020) of *Pterygoplichthys* sp. possess considerable potential as a source of collagen (Fig. 6) for application in the pharmaceutical and cosmetic industries. Heavy metal content (Ramlan et al., 2023) and proximate nutritional analysis (Herath et al., 2020) of collagen were acceptable for pharmaceutical application. However, safety, production, and application of SMC-derived collagen are identified as key areas requiring further investigation (Ramlan et al., 2023). Therefore, Bangladesh's invasive SMCs could serve as potential sources for halal collagen (Nurilmala et al., 2022), as demonstrated by successful collagen extraction from tilapia (*Oreochromis niloticus*) (Akter et al., 2017) and

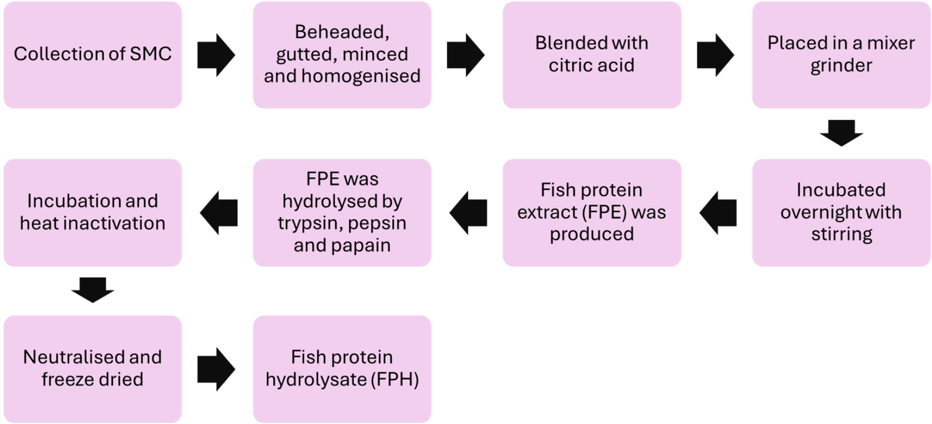

Fig. 5. Process of fish protein hydrolysate (FPH) production from suckermouth catfish (SMC) (modified from Petrova et al., 2018; Wijesinghe et al., 2021).

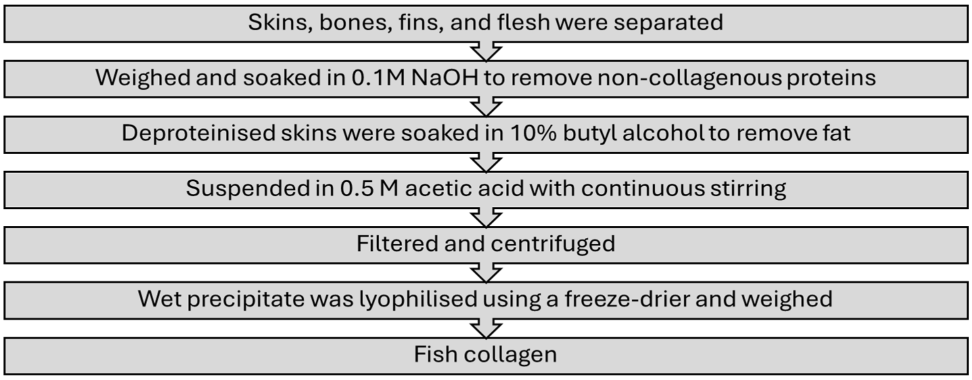

Fig. 6. Collagen extraction process from suckermouth catfish (SMC) (modified from Herath et al., 2020).

carp species including catla (*Catla catla*), rohu (*Labeo rohita*), grass carp (*Ctenopharyngodon idella*) (Hossain et al., 2016).

Gelatine

The technical feasibility of extracting high-quality gelatine from SMC has been established, with studies showing superior gel strength from skin-derived gelatine. Gelatine was produced through the 16 h immersion of fish skin in a solution comprising acetic acid and phosphoric acid (Ranasinghe et al., 2022). Another study demonstrated that catfish bone-derived gelatine exhibited properties comparable to commercial gelatine, with significantly higher concentration yields than gelatine obtained from other fish bone sources (Asmawati et al., 2023). These findings are particularly relevant for Bangladesh, where successful gelatine production from the skin and bones of *Pangasius pangasius* (Barman et al., 2020) has already laid the groundwork for industrial-scale fish byproduct utilisation. Thus, gelatine production from SMC may represent a viable upcycling approach for Bangladesh.

Alkaline protease

The enzymes used in food and pharmaceuticals are usually sourced from mammals and microorganisms due to ease of availability. But now fish are also thought to be the source of exogenous enzymes. *Pterygoplichthys disjunctivus* was first reported by Villalba-Villalba et al. (2011) as a potential enzyme source of trypsin and chymotrypsin (Fig. 7) which are necessary proteolytic enzymes in organisms. Trypsin is highly utilised in carnivores and omnivores (Munilla-Morán and Stark, 1990) whereas chymotrypsin is more

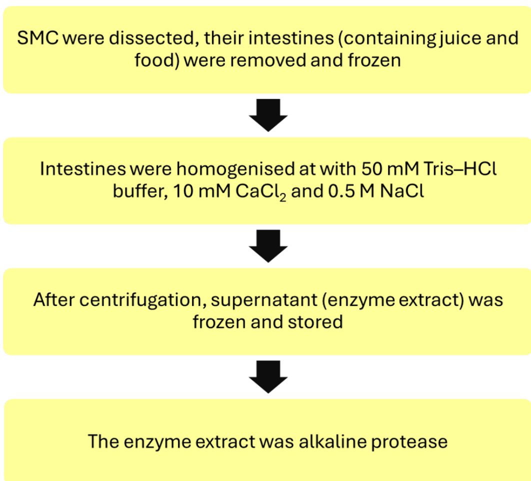

Fig. 7. Process of alkaline protease extraction from suckermouth catfish (SMC) (modified from Villalba-Villalba et al., 2011).

utilised by herbivores (Jónás et al., 1983). Since both enzymes with 60 min of stability at around 50 °C are highly functional in *P. disjunctivus*, these enzymes can be recommended for their extraction and purification from SMCs. In Bangladesh, protease production from fish has been successfully demonstrated through different approaches: Bhowmik et al. (2015) isolated proteases from gut bacteria, while Jainab and Sultana (2021) extracted cellular proteases from rotten dried fish. These established methods suggest that protease extraction from the SMC could represent a feasible new approach for Bangladesh.

The environmental degradation caused by conventional tannery operations, particularly through chemical runoff, has been extensively documented in Bangladesh (Uddin et al., 2015). Alkaline protease enzymes, proven effective in reducing tannery pollution (Sabtecha et al., 2014), could be sustainably sourced from an unexpected reservoir: the visceral byproducts of invasive SMC. This approach transforms an ecological threat into a bioremediation tool while mitigating the leather industry's environmental footprint.

Human food

Typically, fish serves as a significant contributor to human nutrition in terms of protein and micronutrient content (Ariyarathne et al., 2016). Nonetheless, several researchers examined the safety concerns, such as heavy metal concentration, of SMCs as human food (Ariyarathna et al., 2014; Sumanasinghe and Amarasinghe, 2014; Elfidasari et al., 2018).

Flesh and roe

While SMCs are not conventional for fresh flesh, their flesh and roe have the potential to be commercially beneficial (Hoover et al., 2004). Omega-6 fatty acids, which are also nutrient-dense and proteinaceous, are abundant in the flesh (Mengumphan and Saengkrachang, 2008). Additionally, the mature roe of *Pterygoplichthys disjunctivus* are protein and lipid-rich (Guillén-Sánchez et al., 2015). According to Guillén-Sánchez et al. (2021), the roe of *P. disjunctivus* has been identified as a potential human food with its 20-day shelf life when stored in ice.

Loricariids are consumed as food in Brazil, where they are prepared using traditional cooking methods. However, concerns have been raised regarding heavy metal accumulation in these fish, as observed in Laguna de Bay (CEC, 2009). The suckermouth fish species have become a culinary delight for a few food enthusiasts in Bangladesh. Such findings, however, are ecosystem-specific and should not be generalised. In some communities, SMCs are already used in dishes such as ceviche and soups. Their bony external layer complicates processing compared to species like tilapia, but recent adaptations such as solar oven baking have facilitated easier bone removal (CEC, 2009). Nutritionally, SMC provide a valuable protein source and can be processed into diverse products, including fillets, fish balls, satay, pekasam (fermented fish), and dried snacks (Wan Ismail et al., 2024).

Fish biscuits

Since SMCs are popular as aquarium fish, promoting it for human consumption as fresh fish would be cumbersome. However, value-added products of SMC could be healthy human foods (Ariyarathne et al., 2016). Biscuits with fish flour of *Pterygoplichthys multiradiatus* were made (Fig. 8) and compared with normal biscuits. Biscuits with SMC flour were more nutritious, protein-rich, and safe for consumption (Ariyarathne et al., 2016). Fish-based snacks including fish biscuits, mixed savoury snack (Chanachur), and bars were produced from pangus (*Pangasius hypophthalmus*), silver carp (*Hypophthalmichthys molitrix*) and kechki fish (*Corica soborna*) by the researchers in Bangladesh (UNB, 2019; Dried Fish Matters, 2021) which demonstrates the potential to adapt these processing techniques for SMC utilisation. Preliminary evidence suggests that with targeted studies, SMC could serve as a viable raw material for commercial-scale production of fish biscuits and similar type of foods.

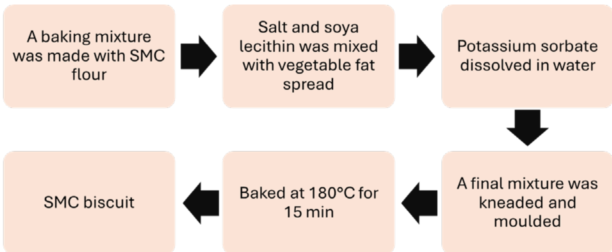

Fig. 8. Process of making fish biscuits from suckermouth catfish (SMC) (modified from Ariyarathne et al., 2016).

Biofuel production

Biodiesel, derived from triglyceride-rich lipids via transesterification, exhibits superior fuel properties compared to petroleum diesel, including higher flash points, enhanced biodegradability, improved lubricity, and greater combustion efficiency (Lin and Li, 2009). As a renewable energy source, it offers a sustainable alternative to fossil fuels. However, the use of food-grade oils for biodiesel production has raised concerns over rising food prices, prompting research into alternative feedstocks such as non-edible vegetable oils, waste oils, animal fats, and food industry byproducts—solutions that also address waste management challenges (Mis Solval et al., 2021).

The soap stock derived from mixed marine fish was utilised as a biodiesel feedstock in studies (Lin and Li, 2009). Similarly, Amazon sailfin catfish (*Pterygoplichthys* spp.) biomass has been identified as a viable low-cost raw material for biodiesel production. This approach not only mitigates atmospheric pollution but also reduces the ecological impact of this invasive species. Despite its low lipid content (7–12 % by weight), the species' rapid growth rate (5–6 months) and high reproductive capacity enable large-scale biomass production in compact spaces, making it economically competitive with traditional feedstocks. Chemical analyses confirm that biodiesel produced from Amazon sailfin catfish complies with the European EN-14214 standard for physicochemical properties and methyl ester composition, ensuring engine compatibility. Crucially, since this species is inedible, its use avoids competition with food production—a significant advantage over other biodiesel sources (Anguebes-Franseschi et al., 2019).

Aquaculture and fisheries industries globally generate significant byproducts, many of which remain underutilised. For instance, recoverable crude oil from processing byproducts—such as those derived from *Ictalurus punctatus* (channel catfish) in the United States—holds potential as biodiesel feedstock, with annual yields estimated in the millions of kilograms (Mis Solval et al., 2021). These findings underscore the viability of repurposing fish biomass from diverse aquatic systems to advance sustainable energy solutions. Facing considerable energy hurdles due to its reliance on imported fossil fuels, diminishing natural gas reserves, and surging demand from industrialisation and urbanisation, Bangladesh could find a promising alternative in biofuels—especially those derived from an underexploited fish species—simultaneously addressing energy security and environmental concerns.

Fertiliser preparation

As part of broader efforts to optimise SMC byproducts, recent research has explored their potential as organic fertilisers. The suitability of *Hypostomus plecostomus* powder as an organic fertiliser was evaluated in a study based on its macronutrient content and growth-promoting effects on vegetable crops. Analytical results revealed that the fish powder contained notably high concentrations of phosphorus (P) and calcium (Ca), key macronutrients for root development and plant structural integrity, exceeding typical levels found in many organic fertilisers. Growth trials conducted on water spinach (*Ipomoea aquatica*) and spinach (*Spinacia oleracea*) demonstrated that *H. plecostomus*-derived fertiliser significantly enhanced plant height, leaf width, and stalk diameter. Its performance was comparable to that of conventional NPK (15:15:15) fertiliser, suggesting its viability as an alternative nutrient source. Furthermore, the fertiliser proved particularly effective in soils with low magnesium (Mg) concentrations, supporting robust growth in both semi-aquatic (*I. aquatica*) and terrestrial (*S. oleracea*) species. These findings highlight its potential for sustainable agriculture, especially in regions where synthetic fertilisers are costly or environmentally detrimental (Fabian Unggang et al., 2023). In Bangladesh, where synthetic fertiliser imports strain foreign reserves and soil degradation is a growing concern, invasive fish-derived organic fertilisers could offer a cost-effective and eco-friendly alternative. Given the country's abundant invasive fish biomass and reliance on agriculture, scaling up such biofertilizer production could reduce dependency on chemical fertilisers while promoting circular economy practices in aquaculture and farming sectors.

Wastewater treatment

Biotreatment of effluent is imperative to save the environment, water resources, and living organisms from pollution (Dixit et al., 2011). Suckermouth catfish are also referred to as a "janitor fish" or "tank cleaner" (Chavez, Casao et al., 2006). Studies reported that *Pterygoplichthys pardalis* can be effectively used to treat sewage water from industries as an environment-friendly method of waste management. The parameters like total suspended solids, total dissolved solids, biological oxygen demand (BOD), and phosphorus are tested to ensure sewage remediation (Kumar et al., 2016). The same species of SMC (*P. pardalis*) was also mentioned by Karthiga et al. (2019) as highly efficient in the biotreatment of sugar industry effluent. However, understanding the mechanisms and improving the efficacy of treatment is suggested for future studies by these authors. Furthermore, precaution is recommended when any non-native species is used as a biological control agent, considering ecological repercussions in the future (Copp et al., 2005). The widespread implementation of effluent treatment plants in Bangladesh has given rise to growing concerns regarding the increasing problem of residual sludge in industrial facilities, as highlighted by Haque (2020). In addressing this issue, using the SMC proves to be environmentally friendly and contributes to the conservation of ecosystems.

Artisanal and cultural product development

Handicrafts

The global leather industry has utilised fish skins and bones, including those from SMCs (*Hypostomus* spp.), for manufacturing decorative leather goods such as handbags and garment accessories. While the skins and bones can be repurposed for these applications, the remaining meat requires proper disposal or utilisation. Fish leather possesses unique qualities that make it valuable for commercial use. Its distinctive zigzag texture, resulting from the criss-crossing fibre structure, provides enhanced elasticity and tear resistance compared to traditional bovine leather (Rahman, 2023). Additionally, the tanning process for fish skins is more environmentally sustainable, requiring reduced chemical inputs and energy consumption due to their naturally thinner composition.

Suckermouth catfish skin demonstrates particular potential for leather production due to its notable durability and aesthetic qualities (Wan Ismail et al., 2024). This material serves as an eco-friendly alternative for manufacturing various products including footwear, belts, and fashion accessories. The skins of larger SMC provide adequate material for various high-value applications, including luxury accessories such as handbags, purses, footwear, and decorative items like ornamental boxes and stationery (Rana et al., 2024). The development of specialised processing facilities could transform this invasive species into a commercially viable resource while addressing ecological concerns.

Souvenir/gifts

The concept of spiritual value in souvenirs encompasses objects believed to bring good fortune or provide protection, with interpretations varying between religious and secular perspectives. These values emerge from cultural traditions, where non-religious symbolic meanings often derive from linguistic associations, visual representations, or folkloric traditions. A notable example is the fish motif in Chinese culture, where the word for fish "yu" shares its pronunciation with the term for surplus, making it a symbol of prosperity and wealth. The reputation of souvenirs similarly influences their appeal through perceptions of authenticity and distinctiveness (Duan et al., 2023).

Suckermouth catfish (SMC) demonstrate remarkable biological adaptations, including the ability to survive in dried mud for extended periods through aestivation (Castro and Life, 2024). This physiological trait suggests potential applications in preservation techniques for decorative purposes. While not traditionally used in craft production within their native habitats, their distinctive armoured morphology presents opportunities for artisanal adaptation, potentially serving as ornamental objects similar to dried pufferfish or seahorses in other cultural contexts.

In South American ecosystems, SMC (known locally as cascudo) occupy important ecological niches. Begossi et al. (2004) documented their cultural significance among Brazilian fishing communities, where their physical characteristics and benthic behaviour have influenced both consumption patterns and dietary restrictions. While some communities utilise them as a food source, others avoid consumption due to associations with scavenging behaviour or negative taste perceptions, reflecting the complex relationship between ecological traits and cultural interpretation. However, this particular upcycling mechanism could be difficult to be adapted in Bangladesh and many other tropical countries for cultural differences.

Use for medicinal purpose: Bone healing

Grafting was performed using hydroxyapatite (HA) obtained from the bones of SMC onto synthetic defects in the femoral bones of rats. Thus, as a substitute for raw bone graft material, SMC bone may have advantageous properties, according to the study; however, further research is required to validate its use as a biomaterial for treating loss (Djamaluddin et al., 2023). In addition to its potential as an engineered biomaterial for bone tissue engineering, HA has a wide range of applications in bone replacement and fillers (Islam et al., 2020). Mamun et al. (2020) reported hydroxyapatite bone grafts among jaw cyst patients in Bangladesh. This finding suggests that hydroxyapatite derived from SMC could be a viable material for medical applications in Bangladesh.

Heavy Metals in Suckermouth Catfish

Ecological factors influence fish's heavy metal absorption and accumulation (Oryan et al., 2011), posing threats to marine ecosystems and human health, with adverse effects on vital organs (Arantes et al., 2016). As mentioned before, the concern for heavy metal contamination in the context of food safety is particularly relevant in the case of SMCs.

Ernawati's (2014) findings in a heavy metal contaminated river indicated that while cadmium and mercury levels in SMC were within recommended limits for human consumption, lead concentrations surpassed safe levels. Large quantities of heavy metals were detected in *Cyprinus carpio* than in *Pterygoplichthus pardalis*, by Castañeda-Chávez et al. (2021). However, in rivers and lakes where heavy metal concentrations fall within acceptable ranges, the levels are lower and meet the required content limits for metal contamination (Amir et al., 2020). In the realm of heavy metal-contaminated rivers, Elfidasari et al. (2023) revealed that the SMC gut bacterial communities help to survive in this harsh environment. They suggested that the SMC might play a role as a potential bioremediatory of heavy metals in river sediments.

According to research, the heavy metal concentrations in canned fish products (Simionov et al., 2023), dried fish, and other fish products (Sivaperumal et al., 2007; Rakib et al., 2021) from different fish did not exceed the maximum allowable values set by the relevant authorities. In contrast, Yulyana et al. (2023) advised against fishing in places with significant pollution to prevent the ingestion of fish products that have been contaminated. Thus, while fish products have historically posed less of a threat, SMC collected from polluted environments can still be used to produce harmful products. As a result, scientists and manufacturers must consider the possibility of heavy metal contamination when engaging in upcycling.

Challenges and Recommendations

The invasion of SMC presents multifaceted challenges that extend beyond local ecological disruptions, affecting global biodiversity, socioeconomics, and sustainable resource management. While the negative impacts of SMC on native ecosystems are well documented — such as competition with indigenous species, alteration of nutrient cycling, and physical habitat degradation (Sarkar et al., 2023; Adeoye and Johnson, 2024) — the complexities of controlling these invaders remain significant and call for a broader perspective. Therefore, we conducted an extensive review of the literature to propose some upcycling techniques for sucker fish for strengthening management efforts.

Ecological complexity and data gaps

In many invaded regions, including Bangladesh and parts of Southeast Asia, the dynamic interactions between SMC and native species are not fully understood. Some studies have pointed out that the biological traits that make these species successful invaders such as rapid growth (Liang et al., 2005; Gibbs et al., 2013), negative allometric patterns (Sudarshan et al., 2022), and high reproductive capacity (Hoover et al., 2004; Gibbs et al., 2008) also exacerbate their impacts on nutrient cycles and habitat structure. However, incomplete data on their population dynamics, long-term ecological impacts, and synergies with other invasive organisms complicate the development of effective control and upcycling strategies. In addition, inconsistencies in taxonomy and misidentification further hinder accurate assessment of the invasion scale and the design of targeted interventions.

Technological limitations and monitoring

Although modern tools like environmental DNA (eDNA) assays (Dali et al., 2023), remote sensing, and machine learning (Rana et al., 2024) have shown promise in detecting and predicting invasive species spread, their application to SMC management remains at an early stage. Yet, implementing such methodologies on a large scale in developing countries is hindered by technological, infrastructural, and financial constraints. Moreover, the high degree of variability in water quality and hydrological parameters in regions like Bangladesh demands continuous monitoring that can be both labour and cost intensive.

Economic and market barriers

Upcycling invasive species into value-added products offers a potentially attractive win-win solution. However, there is often a disconnect between research breakthroughs and market realisation. Consumers in many regions may be hesitant to accept products derived from invasive fish due to cultural biases (Sarkar et al., 2023) and health concerns, especially around issues like heavy metal accumulation in SMC tissues (Rana et al., 2024). Additionally, the economics of upcycling require comprehensive market analysis, supply chain management, and quality certification all of which can be challenging in emerging economies with limited industrial infrastructure. Moreover, despite documented instances of upcycling, particularly in value-added products, their production and application in most countries including Bangladesh remains limited.

Policy and regulatory gaps

In many affected countries, the regulatory framework lags behind the rapidly changing ecological conditions. Although some nations are beginning to impose bans or restrictions on the farming, import, and trade of SMC (as seen in recent actions in Bangladesh and parts of Malaysia) (Bari, 2024; Lee, 2025), enforcement and inter-agency coordination remain weak. Policymakers are frequently challenged by the need to balance economic development with ecological conservation (Orfinger and Douglas Goodding, 2018). Moreover, there is a lack of harmonised international guidelines that address the prevention, monitoring, and management of invasive aquatic species, which complicates cross-border cooperation and data sharing.

Integration of community knowledge

While local communities and fishers often possess valuable traditional knowledge regarding the behaviour and impact of invasive species, this knowledge is frequently underutilised in formal management plans. Bridging the gap between local practices and scientific research is essential for designing interventions that are culturally acceptable, economically viable, and ecologically sustainable (Rana et al., 2024). In regions like Bangladesh, where community engagement is crucial, the lack of coordinated capacity-building programs limits the potential for community-led monitoring and control initiatives.

To address these diverse challenges, an integrated and adaptive management framework should be established. The following recommendations may be of assistance in surmounting the challenges for policymakers and researchers.

Integrated management frameworks

Integrated management strategies should be developed to concurrently address ecological, economic, and social dimensions. Integrated management should be adaptive, continually updated with the latest research and monitoring data, and structured to allow rapid response to emerging threats. Partnerships between governmental agencies, academia, NGOs, and the private sector should be encouraged to foster a multi-disciplinary approach. International collaboration can bring valuable experiences from regions such as North

America and South America (Mamun et al., 2023) where similar species control strategies have been trialled.

Monitoring and research

Investment in high-tech monitoring systems, automated image analysis, and machine learning algorithms could enhance tracking of invasive populations (Hackenberger et al., 2025). These methods offer rapid and cost-effective measures to obtain real-time data, which could be critical for adaptive management. Comprehensive, longitudinal studies should be conducted to fill data gaps regarding population dynamics, reproductive biology, and ecosystem impacts of SMC. Interdisciplinary research should explore how variables such as hydrology, water quality, and interspecific interactions influence invasion success.

Sustainable upcycling initiatives

Marketing strategies should emphasise the nutritional, environmental, and economic advantages of upcycled SMC products, including food (Soteyome and Thedkwanchai, 2023), fishmeal (De Fonseka and Radampola, 2022), collagen (Nurubhasha et al., 2019), and artisanal crafts. Educational campaigns can help overcome cultural barriers and reposition invasive SMC as a resource. Stringent quality assurance protocols should be implemented to address food safety concerns, particularly regarding heavy metals. Research into safe processing techniques and nutritional analyses should be prioritised to ensure that products meet national and international standards.

Optimum utilisation of suckermouth catfish

To maximise the use of SMC resources, key research could focus on: (1) extracting fish oil from processing byproducts, (2) developing expanded food applications including bakery products, and (3) conducting comprehensive nutritional analyses of local SMC populations. Comparative studies of different SMC species' biochemical composition would enhance utilisation potential. Additionally, pilot studies should examine SMC's potential in effluent treatment systems to support green industrial practices.

Policy, regulation, and enforcement

Regulatory measures restricting the import, breeding, and release of invasive aquarium fish should be established and enforced. Regulations informed by ecological risk assessments aim to minimise propagule pressure in the ornamental fish trade. International platforms could be created for information sharing, joint research, and coordinated action among countries affected by SMC invasions. Increased funding and support for local enforcement agencies to monitor and control the illegal release of aquarium fish could be effective for control.

Traditional knowledge and community engagement

Local communities should be empowered through participatory management programs that leverage traditional ecological knowledge. Training and co-management agreements can help integrate local insights into scientifically informed management plans (Peacock et al., 2020). Outreach programs designed to educate communities about the negative ecological impacts of SMC, and the potential benefits of upcycling could be launched.

Conclusion

Globally, invasive Suckermouth catfish (SMC) threaten aquatic biodiversity and aquaculture, with Bangladesh representing a particularly affected region. Despite governmental responses, controlling SMC proliferation remains challenging due to monitoring difficulties and underutilisation of SMCs. This highlights the urgent need for adaptable upcycling strategies that can convert ecological threats into sustainable resources through localised application of international knowledge. By compiling and analysing global practices, this review presents a comprehensive evaluation of SMC upcycling opportunities for Bangladesh. In Bangladesh, four species (*Hypostomus plecostomus*, *Pterygoplichthys pardalis*, *Pterygoplichthys multiradiatus* and *Pterygoplichthys disjunctivus*) belonging to two genera (*Pterygoplichthys* and *Hypostomus*) have been documented. While there is concern regarding heavy metal pollution, which varies depending on the source, protein rich SMCs can be utilised in various ways as raw materials in the production of numerous animal and human consumables or value-added products.

Furthermore, biofuel production, organic fertiliser development, sewage biotreatment, and potential cultural and medicinal applications using these invasive fish were also identified as upcycling possibilities. However, upcycling is suggested only to use and deplete the SMC populations in natural systems, not to encourage their aquaculture. The potential for SMCs to undergo various upcycling processes could present prospects for increasing the capture of the SMC population, thereby facilitating the efficient implementation of control measures. This discussion can help the vested authorities and researchers formulate control strategies to neutralise the threat posed by SMCs.

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Writing-review and editing, Md. Shoebul Islam: Resources and methodology. SM Abdullah Al Mamun: Visualisation and software. S.M. Rafiquzzaman: Conceptualisation, visualisation and supervision.

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