



A conceptual framework for community-based reporting and bio-resource conversion for invasive freshwater fish control in agribusiness

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ARTICLE INFO	ABSTRACT
Paper Type: Research Paper Received: 13 July 2026 Revised: 01 August 2026 Accepted: 27 August 2026 Published: 25 September 2026 Keywords Bio-resource conversion Circular bioeconomy Community-based environmental monitoring Environmental decision-support analytics Invasive freshwater species management Corresponding author: Fathin Nabilla Md Leza fathin@utem.edu.my	Invasive freshwater fish species, particularly suckermouth catfish (ikan Bandaraya), disrupt Malaysian freshwater ecosystems by competing with native species, altering food chains, and threatening biodiversity. Despite the ecological risks, there is a lack of a structured mechanism to monitor, control, and convert invasive fish into sustainable products for agricultural and aquaculture businesses. Current conventional fish removal efforts are inefficient because fish hunters search randomly, resulting in wasted time, resources, and biological materials. This study adopted a qualitative design involving stakeholder consultations, semi-structured interviews with representatives from Skuad Pemburu Ikan Asing (SPIA), a literature review, conceptual framework development, and a demonstration of an early-stage prototype. The study proposes a conceptual framework integrating community-based fish reporting through geotagging, coordinated fish hunting and control, processor distribution, proposed bio-resource conversion tracking, and marketplace analytics within a unified workflow. The framework is designed to support end-to-end traceability by linking captured invasive fish to proposed bio-resource conversion pathways for value-added products such as organic fertilizers and aquaculture feed. It also provides analytical information to support ecosystem management and restoration planning. The framework aligns with Sustainable Development Goals 14, 12, and 8 and promotes a circular bioeconomy by reducing ecological waste and creating opportunities for sustainable resource utilization.
	How to cite this paper: Leza F. N. M., Zabri A. S. M., Mozamir M. S., Rahman M. H. A., Hasan K. H. A., Rodzoan M. A. B., Sofiadin A. B. M., (2026). A conceptual framework for community-based reporting and bio-resource conversion for invasive freshwater fish control in agribusiness. <i>Environ. Water Eng.</i>, 12(2), 253-266. https://doi.org/10.22034/ewe.2026.245347

1. Introduction

In many freshwater ecosystems across the world, invasive freshwater fish species are becoming a major ecological concern (Britton et al., 2023). One such invasive species that has a significant presence is the suckermouth catfish (ikan bandaraya), which is the most commonly reported freshwater invasive fish in Malaysia, as it rapidly disperses into rivers, lakes, and reservoirs (Sulaiman & Yusof, 2024). These invasive species disrupt the local freshwater ecosystems by competing with native fish for food and habitat, modifying the natural conditions of their habitats, thus impacting freshwater biodiversity.

Over time, extreme population increases in invasive fish species could destabilize the food chains of ecosystems and endanger sustainable populations of native fishes (Britton et al., 2023; Aziz et al., 2026; Mohammad et al., 2024). Furthermore, despite heightened awareness of ecological risks due to invasive fish populations, the monitoring and control of these species remain challenging. In many local contexts, detection and eradication are still reliant on manual observations or sporadic fishing by local communities and fish hunters (Benjamin et al., 2025). Such practices, however, often lack the coordinated management approaches and standard reporting mechanisms required to monitor the spread of invasive species or assess the success of fish control measures.

In practice, fish control strategies for invasive fish mostly occur in phases. Fish hunters handle removal efforts independently; the community (i.e., the public) may report sightings through informal means (e.g., social media), and caught fish are often discarded upon capture via burial, since there are no organized channels for processing or distribution (Adeli et al., 2026; Benjamin et al., 2025; Zasko & Emelyanov, 2026). These fragmented operations result in inefficiency in the duplicative search for invasive fish, wasted manpower, fuel, and travel time costs, as well as the loss of potentially valuable biological resources (Britton et al., 2023).

Moreover, without integrated reporting and monitoring systems, it is difficult for environmental authorities to monitor the spread of invasive species and identify high-risk areas. Without traceability and systematic data collection, it becomes challenging to have community reporting transform its findings into meaningful insights for decision-making (Sulaiman & Yusof, 2024).

Without continuous data collection efforts and coordination of reporting mechanisms, local authorities and environmental agencies often have to resort to opportunistic removal programs or periodic monitoring surveys. As a result, invasive fish species can remain undetected for extended periods of time, during which their populations thrive and colonize nearby inland freshwater ecosystems, such as small rivers, lakes, and watercourses. The absence of unified control and operational coordination further limits the processing of captured invasive fish species, resulting in the waste of biological resources and missed opportunities for sustainable bio-resource utilization. For this reason, control activities are often reactive rather than systematized, undermining the overall effectiveness of invasive species management efforts.

Invasive fish species are widely regarded as ecological threats, but they also offer economic opportunities through bio-resource conversion. Invasive fish can be converted into agricultural and aquaculture products such as fish feed, organic fertilizers, and other biomass-based materials (Unggang et al., 2023). They can be processed into biomass through methods such as grinding, fermentation, or drying for use in producing organic fertilizers and aquaculture feed. This reduces environmental pollution while converting biological waste into value-added products, thus promoting the circular economy. Hence, a coordinated mechanism that integrates fish control, capture operations, resource processing, and distribution to end users is needed to fully realize this opportunity. As caught fish are most likely to be discarded without integrated workflows, a unified framework that coordinates these efforts could allow more effective control of fish capture operations, resource traceability, and community-driven ecosystem management while supporting circular bioeconomy initiatives.

In this study, we identified that there is a lack of systematic frameworks that integrate community-based reporting, fish control coordination activities, resource distribution, processing traceability, and analytical decision-making. Most

existing practices concentrate only on discrete facets of resource processing or environmental monitoring, with little integration throughout the entire operational lifecycle of invasive fish management. In addition to decreasing operational efficiency, these fragmented operations prevent stakeholders from making decisions using data-driven insights for ecosystem restoration initiatives.

To address this issue, the study proposes a conceptual integrated framework that connects community-based fish reporting, invasive fish control coordination, proposed bio-resource conversion pathways, and marketplace analytics within a unified operational workflow. The proposed conceptual framework connects three core operational processes, which are designed to support coordination, resource traceability, and environmental decision support rather than to introduce a new computational algorithm.

Hence, the aims of this study are to integrate community-based reporting with invasive fish control activities, establish a traceable operational workflow across proposed bio-resource conversion pathways and processor distribution, and incorporate analytics to support environmental decision-making and ecosystem restoration planning. The scope of this study is limited to the proposed conceptual framework development and an early-stage prototype demonstration. Detailed quantitative evaluation measures and operational validation are beyond the scope of the present work and are identified as future research. In the next section, we present a literature review of related work. The subsequent sections detail the methodology in Section 3, results and discussion in Section 4, and the conclusion and future work in Section 5.

2. Related Work

Traditional field survey methods, such as electrofishing, gill netting, and visual observation, and the firsthand knowledge of local fishers, agency employees, and community members, have historically been crucial to monitoring and control (Benjamin et al., 2025). Invasive freshwater fish pose a major threat to biodiversity and the functioning of ecosystems, requiring effective control and removal strategies (Bernery et al., 2022). Recent studies have also explored several approaches to controlling these invasive populations. Britton et al. (2023) highlighted that the most effective management measure to protect freshwater biodiversity is to prevent introductions of non-native species (Britton et al., 2023).

This is crucial to minimize further impact, to reduce invasive fish abundance, to restrict spread through screening of affected areas, and to implement strict biosecurity to prevent the invasion of neighboring areas (e.g., rivers and waterways) (Mohammad et al., 2024; Manzoor, 2026). For example, in Box Canyon Reservoir, Washington, Northern Pike populations have been successfully suppressed by physical removal techniques such as gill netting, which has resulted in a notable decline in their abundance over several years (Bean et al., 2024).

Similarly, the Great Lakes' sea lamprey control program has successfully decreased the lamprey population by using a combination of pesticides and in-stream barriers, although these techniques may have negative effects on non-target species (Wilkie et al., 2022; Wahyuningtyas et al., 2026). However, these methods can harm existing native fish populations, particularly when using non-selective removal. Specifically, non-selective methods such as gill nets and chemical treatments may cause injuries to native fish and lower their survival potential in their natural habitat (Erickson et al., 2023; Jones et al., 2021).

According to Adeli et al. (2026), must-kill fishing laws have been implemented in several nations to control invasive fish populations; however, their efficacy is still largely anecdotal and needs careful evaluation (Adeli et al., 2026). To minimize the spread and impact of invasive freshwater fish, long-term control and containment measures are combined with prevention, early detection, and prompt response to new invasions (Britton et al., 2023). Strategies include establishing regulatory frameworks and performing horizon scanning across rivers or waterways to identify potential threats, especially non-native species that may arrive from affected areas (Britton et al., 2023). This approach also assesses the likelihood of future threats and impacts on ecosystem services (Britton et al., 2023).

In addition, advanced early detection techniques using environmental DNA (eDNA) are being deployed in high-risk areas such as urban centers and ports (Waltham et al., 2023). These techniques can screen several species rapidly at low cost (Gold et al., 2021). Nonetheless, although prevention and early detection are ideal, they are often ineffective once the species has become established. According to Khaleel et al. (2021), the invasive Peacock Bass in Malaysia is of concern and requires a permanent strategy to control and manage the population (Khaleel et al., 2021).

In Malaysia, Non-Governmental Organizations (NGOs) and local communities frequently monitor invasive freshwater fish through field surveys, manual observation, and removal campaigns. Instead of using organized data-driven monitoring, conventional fish removal efforts by fish hunters often involve inefficient, random searching (Unggang et al., 2023). Another study also emphasizes population control programs and physical removal techniques to lessen ecological harm (Khaleel et al., 2021). Nevertheless, these methods lack systematic data collection and long-term monitoring mechanisms, and they are frequently reactive and spatially constrained due to a lack of accurate geo-location data of the affected areas. Consequently, current conventional fish removal efforts lack structured, systematic mechanisms for monitoring and often fail to provide coordinated reporting and integrated management (Unggang et al., 2023).

Recent studies by Ceca et al. (2026) and Chala et al. (2026) explore the possibility of extending invasive species management beyond isolated detection or removal activities. Based on the management of invasive blue crabs, these studies

highlight the importance of stakeholder collaboration in coordinated monitoring, socioeconomic impacts and valorization routes, although operations remain fragmented between multiple agencies and sectors (Ceca et al., 2026).

Similarly, another study has shown that more than 75% of the biomass of the water hyacinth from the removal campaign was still above the level of infestation even after the removal had been extended within a year, demonstrating that the interim control without long-term monitoring and unified management workflow only serves as a temporary control measure (Chala et al., 2026). These findings suggest that sustainable practices in invasive species management such as continuous monitoring, coordinated operations, use of resources, and feedback from stakeholders are necessary to achieve effective holistic control rather than just removing invasive species alone.

Meanwhile, community-based reporting platforms and citizen science methods are becoming increasingly prevalent in contemporary environmental monitoring systems (F. N. Leza et al., 2026). [Ma1.1] This has also been supported by Britton et al. (2023), who note the growing role of community-based approaches in environmental monitoring (Britton et al., 2023). These methods enhance real-time detection of environmental problems, such as ecosystem disturbances and wildlife sightings, as well as spatial coverage. Nonetheless, many communities reporting systems only record observations during the data collection phase and do not incorporate them into operational management workflows. This may result in underutilization of useful environmental data produced by the community, which is frequently overlooked, preventing proactive coordinated action and informed decision-making.

On the other hand, citizen science facilitates spatial and temporal coverage of biodiversity for environmental monitoring of invasive species and conservation activities (Flister et al., 2026; Lusk et al., 2026). Recent studies describe the impact of different levels of participation, variations in observer behaviour, taxonomic preferences, geographical distribution, and quality verification on crowdsourced datasets (Flister et al., 2026; Lusk et al., 2026). These studies emphasize the integration of expert validation, structured surveys, and environmental data to increase the reliability of community-generated observations. Thus, community-based reporting should support the need for a verification process before using reported sightings of invasive species for control activities and data-driven decision-making, rather than replacing formal monitoring.

The transformation of biological waste into valuable agricultural products, such as compost, animal feed, or organic fertilizers, has been the subject of different studies. Censi et al. (2025) suggest the use of digital technologies in agri-food waste management, which provides promising opportunities for circular economy applications, including pyrolysis and anaerobic digestion that can diminish systemic inequality and improve the sustainable development objectives (Censi et al., 2025). This is further supported by Peng et al. (2025), who

highlights the role of the circular economy in agriculture (Peng et al., 2025), emphasizing innovations like biomass utilization and anaerobic digestion to lower carbon emissions and improve sustainability.

Sreedhar et al. (2025) also discuss the revolutionary potential of big data analytics in organic waste recycling, pointing out obstacles, such as inadequate infrastructure and poor source segregation, and suggesting community involvement and policies to improve data-driven waste management methods (Sreedhar et al., 2025). However, these analytical methods and tools in agribusiness usually concentrate on supply chains, market demand, and production efficiency rather than on ecosystem monitoring and its role in integrated invasive species management. There is also a lack of discussion on invasive species forecasting in relation to the downstream bio-resource utilization of captured fish.

In the context of invasive fish species, captured fish have been investigated as possible sources of aquaculture feed, agricultural inputs, and diverse end-products (Khaleel et al., 2021; Unggang et al., 2023). For instance, in Malaysia, some studies demonstrate how invasive species such as peacock bass and suckermouth catfish can be converted into bio-resources, which would reduce ecological waste and promote sustainable agriculture (Khaleel et al., 2021; Unggang et al., 2023). Additionally, agribusiness systems use advanced analytics and business intelligence tools to track market demand, supply chains, and production (Rahman & Hye, 2022; Raji et al., 2024). Nevertheless, rather than monitoring ecosystems, these analytical systems usually function after resource processing, concentrating on commercial outcomes (e.g., profits, production, and markets) over real-time ecosystem monitoring (Uyar et al., 2024). This has led to a fragmented operation of environmental monitoring systems, invasive fish control, and bio-resource conversion, thus impeding integrated processes for the restoration of biodiversity and the sustainable use of resources.

More recently, a study by Muslim (2026) demonstrates the potential to support national-level material flow planning and circular economy strategies. The study utilizes AI-driven predictive modelling to forecast macro-level resource flow indicators (Muslim, 2026). However, the study does not address how community-based environmental monitoring or traceability for bio-resource conversion can facilitate the forecasting of resources, thus highlighting the need for integrated digital platforms as a unified operational workflow from community-based reporting to downstream bio-resource utilization and decision-support analysis.

Apart from that, another recent study by Madjid et al. (2026) studied the ecological impact of river sand mining by integrating governance indicators with environmental monitoring to assess degradation (Madjid et al., 2026). The study discusses the importance of governance and monitoring to promote environmental conservation. Nevertheless, there is a lack of community engagement and resource recovery

mechanisms in the study; instead, it concentrates on monitoring environmental impacts after resource extraction. Conversely, the proposed framework extends environmental governance by integrating community-based reporting and proposed bio-resource conversion pathways into actionable insights through decision-support analysis.

Additionally, this was supported in a previous study by Salih et al. (2025) which stressed that environmental information is crucial as it provides factual evidence for environmental governance and supports decision-making (Salih et al., 2025). It incorporates legal and cybersecurity challenges to preserve environmental data integrity. Nonetheless, it neither addresses the collection of environmental data through community engagement nor transforms it into actionable insights. This constraint, therefore, represents a significant gap which the current study aims to address.

Converting aquatic biomass into useful end-products is becoming increasingly positioned for circular bioeconomy strategies. Several studies have explored pathways for converting aquatic biomass into products such as feed, fertilizers, compost, biochar, biomaterials, chitin, chitosan, bioactive compounds, and other biomass-derived products (Cao et al., 2025; Villar-Rúa et al., 2026; Yemmen et al., 2026). However, biomass valorization should not be assumed to always be economically or environmentally viable. This is because process performance depends on the conversion technology used, energy and chemical requirements, logistics, biosecurity controls, market demands, and technological maturity.

Despite many advanced conversion methods remaining at laboratory or pilot scales, flawed economic incentives may unintentionally encourage the cultivation or spread of invasive species. Hence, bio-resource conversion should be integrated with removal and traceable processing operations before large-scale implementation for effective invasive species management and circular economy integration.

Several similar experimental studies further discussed the conversion of invasive aquatic biomass into end-products. Studies by Baldi et al. (2025) and Barontini et al. (2026) have examined the conversion of invasive aquatic plant biomass into value-added products, including unconventional fertilizers and hydrothermal carbonization products that increased crop yield and soil-amendment applications (Baldi et al., 2025; Barontini et al., 2026). On the other hand, resource recovery of wastewater from seafood processing has also produced protein-rich microbial biomass with potential applications in aquaculture, while removing nutrients and organic matter from the wastewater stream (Olyslaegers et al., 2026). Although these studies highlight the technical potential for waste-to-resource conversion, they are limited to specific feedstocks and processing conditions, and they lack discussion of the operational coordination needed to link processor distribution, bio-resource conversion, invasive species control, and market-oriented analytics.

Based on these existing studies, we identified literature gaps in the monitoring of invasive fish, community reporting, and the use of bio-resources. While community reporting systems rarely go beyond observation and documentation, monitoring approaches frequently lack structured reporting and data integration. In addition, bio-resource conversion work usually concentrates on commercialization and processing of end-products rather than ecosystem restoration or environmental monitoring. Moreover, while many analytical tools are increasingly being used in environmental management and agribusiness, they are commonly applied after data collection or the resource processing phase rather than being integrated into the operational workflow of invasive species management (Muslim, 2026; Rahman & Hye, 2022; Raji et al., 2024).

Due to these fragmented operations, ecological data, invasive fish control, resource utilization, and analytical decision support are generally addressed through separate workflows. Existing approaches commonly emphasize one or more specific functions, such as species detection and removal, community-based reporting, biomass valorization, or analytical decision support, without linking these functions across the complete operational lifecycle.

In contrast, the proposed conceptual framework integrates community-generated reports, fish control activities, processor distribution, proposed bio-resource conversion pathways, marketplace functions, and analytical decision support within a single traceable operational workflow. Therefore, the main contribution of this study lies in the operational integration of these previously separated functions rather than introducing a new monitoring technology or predictive algorithm. This integrated perspective provides a conceptual basis for connecting environmental monitoring with downstream resource management and ecosystem decision support.

3. Methodology

This study was carried out in several phases. A qualitative approach was adopted, which included several stakeholder consultations, literature synthesis, conceptual framework design, prototype development, and conceptual workflow demonstration. The first phase involved initial observations of current practices and interviews with relevant stakeholders, including a consultation with a representative from the Ministry of Fisheries and online interviews with four representatives from the NGO, Persatuan Skuad Pemburu Ikan Asing (SPIA), to identify the main barriers to controlling invasive freshwater fish.

The four SPIA representatives were part of the initial requirements elicitation process. Two of the same four SPIA representatives participated in the prototype evaluation, and they continued to be involved with the project throughout the requirements phase as well as during the demonstration of the prototype. The Ministry representative was only involved in the initial stakeholder consultation but did not participate in the prototype evaluation.

The Microsoft Teams platform was used to conduct semi-structured stakeholder interviews, which lasted approximately two hours. The purpose of the interviews was to gather information about current reporting and fish-control procedures, practical difficulties, operational practices, and stakeholder needs for the suggested framework.

Purposive sampling was adopted in the study, and the interviewed participants were experienced fish hunters who were actively involved in invasive fish hunting operations. Interview participants were chosen for their field expertise in fish hunting, field verification, working coordination, and distribution of captured fish. The interview comprised five semi-structured thematic areas: current fish control practices, challenges, tools and technologies used during fish reporting, bio-resources processing and distribution practices, and the expectations of technological support for future operations.

Participation was voluntary, and all participants were informed of the study's objectives and the procedures for documenting their responses. With the consent of the participants, the online interviews were video recorded using the Microsoft Teams recording function. The researchers also took handwritten notes during the session to capture responses to the semi-structured questions. Following the interview, the recordings and notes were reviewed, and the responses were consolidated and transcribed in Google Docs according to the interview questions. The research team discussed and summarized the consolidated responses to support the requirements analysis.

Formal institutional ethical approval was not obtained for this preliminary stakeholder consultation, and no formal exemption or waiver was sought or issued by the institution. The interviews were conducted solely for requirements elicitation and conceptual framework development and did not involve experimental interventions or the collection of sensitive personal data. The findings are presented only in aggregated form, without revealing any personally identifiable information. The two SPIA representatives who participated in the stakeholder consultation and prototype evaluation and were included as co-authors of this study contributed operational knowledge and provided practical input to the development and refinement of the proposed framework. However, due to their dual roles, there is a potential for researcher-participant bias in the study.

Subsequently, the responses were recategorized into recurrent operational themes to identify existing practical challenges in invasive fish control operations and the participants' expectations. These interviews revealed several operational limitations, such as the lack of systematic tracking of captured fish resources, ineffective coordination between fish hunters and processors, the absence of structured reporting mechanisms, and the presence of erroneous geo-location data. The need for accurate geo-tagged reporting, centralized monitoring, bio-resource inventory management, and analytical reporting was highlighted during the interviews to support future operations. Hence, the identified operational

processes from the responses to the interviews were then analyzed to derive system requirements, which in turn were translated into the proposed conceptual framework consisting of three core processes.

Following the identification of this problem, a literature review was conducted to examine existing approaches to circular bio-resource utilization models, invasive freshwater management systems, and community-based environmental monitoring. Based on the literature gaps identified, a conceptual framework is proposed to link these core processes in a single digital workflow. A prototype architecture was then designed and implemented to demonstrate the framework.

The prototype consists of three main modules. The Fish Reporting module uses geo-tagged community reports to support the verification and coordination of fish control activities. The Processor Distribution module manages the allocation and traceability of captured fish to the processors and records intended bio-resource conversion activities. Finally, the Marketplace and Analytics module represents a proposed marketplace pathway for potential end-products to consumers and provides analytical dashboards for environmental monitoring and decision-support analysis.

The framework was developed using a layered architecture to support the implementation of the system and data integration. MongoDB is used to facilitate flexible storage of geolocation data and multimedia inputs including images and videos submitted during reporting and operational activities. Business intelligence tools (e.g., Microsoft Power BI) are used to develop visual analytics that allow stakeholders to monitor trends in fish sightings, proposed bio-resource conversion records, proposed marketplace activities, and spatial reporting patterns. These tools provide interactive geospatial visualization and cross-analysis to support decision-making in environmental monitoring.

Then, the conceptual workflow was tested and demonstrated to SPIA representatives as a software prototype through an end-to-end walkthrough of the proposed core processes. This demonstration covered the functionalities proposed in the framework, namely how the verified reports direct the targeted fish control efforts, how the community reports trigger the monitoring process, and how the proposed processing pathway for bio-resource products derived from captured fish is presented through the framework. Following this, the feedback received was used to assess whether the participating stakeholders perceived the proposed workflow as addressing their operational challenges in practice and the requirements from the interviews. This demonstration provided a preliminary stakeholder evaluation of the proposed framework without conducting a quantitative assessment of the prototype usability or operational performance.

Subsequent to the development of the prototype, a physical demonstration session was conducted with two representatives from Skuas Pemburu Ikan Asing (SPIA). The functional prototype was demonstrated through a comprehensive end-to-

end walkthrough of the reporting, processor distribution, marketplace, and analytics workflows. The approximately one-hour session was conducted to obtain qualitative stakeholder feedback on the perceived operational suitability of the proposed workflow and the functionality of the prototype, rather than to undertake formal statistical validation.

Qualitative feedback collected during the demonstration was analyzed using a manual thematic coding approach. The initial coding process was conducted by one researcher from the team, who reviewed the documented stakeholder comments and assigned an initial code to each comment based on its operational relevance. A second member of the research team then reviewed all of the coded data as well as the emerging themes. The data were not independently coded by each researcher. Where differences in interpretation occurred during the review process, the two researchers referenced their original recordings, field notes, and documentation of the stakeholders' comments to resolve these differences through discussion until agreement was reached. The agreed codes were next categorized into broader functional themes based on their conceptual similarity and mapped to the corresponding prototype functions and improvement areas, including geo-tagging accuracy, marketplace integration, user interface (UI) usability, and analytic capability.

As the main purpose of the demonstration was to obtain preliminary exploratory feedback from stakeholders on the prototype that would guide subsequent refinements, standardized quantitative usability questionnaires, inter-coder reliability, or validation methods were not included in the session. This qualitative approach was designed to ensure methodological transparency, and traceability to provide sufficient detail for conceptual framework design rather than to achieve any statistical generalization.

Preliminary observations from both participants suggested that they perceived the proposed conceptual workflow as broadly reflecting current operational practices, and no major structural changes were recommended. Feedback received was mainly focused on refining the functionalities of the prototype to support future deployment and subsequent feasibility assessment. These opportunities for enhancement are discussed further in the following section, in which the proposed framework and preliminary evaluation will be described in detail, and a discussion on the framework impact and limitations will be presented.

4. Results and Discussion

4.1 Conceptual framework

Based on the literature gaps identified and stakeholder interviews, a conceptual framework is proposed consisting of three core processes: Fish Reporting, Processor Distribution, and Marketplace Analytics. The proposed framework aims to link community-based reporting, fish control activities, processor distribution, resource utilization, and marketplace analytics in an integrated workflow. The framework creates a

coordinated data flow where information collected from community reports directly informs fish control actions and subsequent processing operations, rather than treating the monitoring of invasive fish and resource utilization as separate activities. Therefore, this integration allows for the continuous interconnection of information associated with the proposed bio-resource conversion pathways, operational activities, and environmental observations through systematic data infrastructure flow.

Figure 1 presents a systematic workflow designed to coordinate the management of invasive freshwater fish from capture to the proposed bio-resource conversion pathway and marketplace analytics. It illustrates the workflow from start to finish, with the roles of users and access to specific phases of the core components of the three main modules; Fish Reporting, Processor Distribution, and Marketplace Analytics.

The process begins with the Fish Reporting Module, which serves as the main source of data collection for the system. This phase consists of real-time reports from the community (public) of invasive fish sightings through geo-tagged submissions, including location coordinates, photos, and structured observation information. These reports serve as the first alerts from the communities. The system then stores community-generated reports, which can provide early warning of the presence of invasive fish in different water bodies by collecting precise geolocation data and detailed reports (e.g., descriptions, photos, and videos).

In the framework prototype, report verification is performed manually by authorized stakeholders, such as fish hunters and not through an automated or rule-based engine. The verifier assesses the submitted photographic evidence, geo-location data, and priority level of the reported issue before deciding whether the report is sufficiently reliable to allow for further operational follow-up. The prototype records the verification status and supporting documentation. However, the actual verification process remains human-led because the assessment of submitted evidence involves a degree of subjective judgement by experienced fish hunters, particularly in terms of image quality, locational consistency, and the relevance of the submitted sighting. Therefore, automated or rule-based verification is beyond the scope of the current prototype.

The verification is crucial, as it is intended to improve the reliability of community-based reports by reducing duplicate reports or inaccurate submissions before operational planning begins. Once verified, the fish hunters can plan capture operations by using validated information to identify targeted hunting locations. The creation of hotspot maps that show regions with frequent invasion activity is made possible by the clustering of geo-location concentration patterns of invasive fish sightings that are revealed over time by accumulated community-reporting data.

Next, the Processor Distribution module focuses on coordination and traceability of captured invasive fish resources. Once fish hunters have successfully captured

invasive species based on verified reports, the caught fish are assigned to verified processors for further processing. The captured fish details (e.g., weight, size, and species variations) are recorded in the system prototype, and verified processors are assigned according to their processing capabilities. To support the production of agricultural inputs, the framework outlines potential bio-resource conversion pathways through which captured fish may undergo processing activities such as cleaning, grinding, and dehydration.

Within the proposed pathway, the captured biomass could potentially be processed by suitable processors into products including organic fertilizers, aquaculture feed components, and other bio-based agricultural inputs. These conversion pathways are presented solely to support operational coordination and traceability; the present study did not experimentally conduct or validate the physical conversion processes or the resulting products. By representing and recording these proposed processing operations, the system framework is designed to support the traceability of the captured biomass across the proposed conversion pathway. This phase is intended to address a major operational gap that commonly exists in conventional fish control methods, where a lack of a coordinated processing network leads to inefficient discarding or distribution of caught fish (Barbosa et al., 2024).

The Processor Distribution module provides a structured workflow for allocating captured invasive fish to verified processors according to their processing capabilities and intended bio-resource outputs (e.g., fertilizers, aquaculture feed, agricultural inputs, or other end-products). The system prototype is designed to document processing activities, including the quantity of captured fish, the intended bio-resource output, and the proposed processing schedule. This documentation establishes a conceptual basis for traceability from fish capture across the proposed bio-resource conversion pathways by enabling these activities to be recorded and monitored within the system. Thus, this process is intended to reduce operational fragmentation and increase transparency, as this traceability could support stakeholders in conducting future assessments for the processing efficiency of different processors.

The final stage is the Marketplace and Analytics module. This module conceptualizes a digital marketplace for potential products that could be derived through the proposed bio-resource processing of invasive fish, including fertilizers, aquaculture feed pellets, and other bio-based products. Rather than disposing of the material as biological waste, the proposed marketplace mechanism illustrates how potential bio-resource outputs could be linked to future agriculture and aquaculture supply chains. Additionally, the framework represents a proposed mechanism through which processors could potentially list proposed bio-resource products for prospective users, such as farmers, agricultural suppliers, and other end users. This component supports the circular economy concept by providing a proposed pathway through which ecological waste could be converted into products with potential

commercial value and by reducing environmental disposal issues (Cabrita et al., 2024). Hence, the marketplace component is presented only as a proposed distribution mechanism, rather than evaluating the market demand, profitability, product safety, or the economic feasibility of the proposed bio-resource products in this study.

In addition to representing the proposed products in the marketplace, the proposed framework provides analytics dashboards that deliver insights for administrators and stakeholders (e.g., the Ministry of Fisheries and environmental organizations). Trends in reporting volume, the geographic distribution of invasive fish sightings, proposed bio-resource conversion records, proposed marketplace activities, and waste-reduction indicators are presented as visual indicators.

These analytical insights are intended to assist the stakeholders in identifying priority intervention areas and monitoring fish control activities by visualizing these indicators in the dashboards and hotspot maps. Based on the identified spatial patterns of invasive fish from the community reporting, these analytical outputs are intended to support stakeholders in identifying future intervention areas and assessing the efficacy of ongoing fish control activities.

Moreover, after invasive populations have been reduced, the insights could support ecological restoration planning, which includes determining suitable ecological conditions and locations for the release of native fish species into water bodies (Engelstad et al., 2022). Thus, the proposed framework establishes a conceptual data-driven feedback loop as an ongoing cycle in which operational activities, community-generated reports, and analytical insights continuously guide future ecosystem management and restoration initiatives.

Figure 1 illustrates the core process of the proposed framework, which describes its end-to-end operational flow. It begins when a community member submits fish sighting reports in the Fish Reporting module. After the reports are verified by the authorized fish hunters, the process progresses to coordinated fish control activities. Captured invasive fish are then assigned to registered processors according to the proposed bio-resource conversion pathway.

The proposed bio-resource products are represented in the framework as potentially being distributed to end-consumers through the marketplace channel. These operational activity data are recorded throughout these stages for consolidation into analytical dashboards that support subsequent ecosystem monitoring and restoration planning.

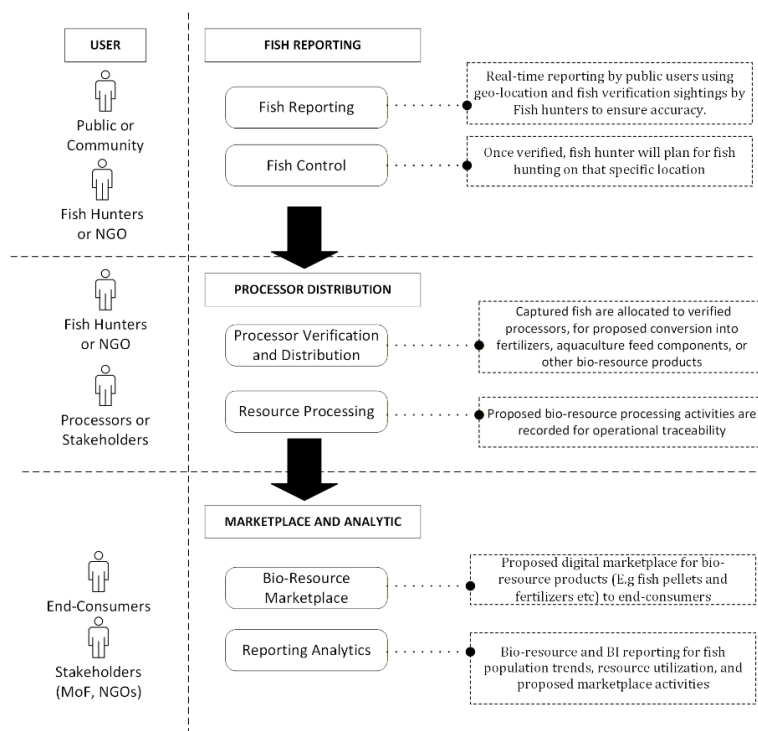


Fig 1. Conceptual framework core process

While Figure 1 represents the end-to-end operational workflow of the conceptual framework, Figure 2 depicts the simplified system architecture supporting the digital implementation of the same proposed workflow. The architecture illustrates how a user role interacts with the system via web or mobile devices and how the three core application modules are linked to data storage, analytics, and role-based outputs.

The five primary components of the architecture include the user roles, the access interface, the application layer, data storage, and analytics and reporting. Public users, fish hunters, processors, stakeholders, and consumers may access the system through web or mobile devices. User authentication for registered operational users is required, whereas public users may report community-based issues without being required to

authenticate. The application layer provides support for three primary functional areas, which are Fish Reporting, Processor Distribution, and Marketplace and Analytics.

Information related to the reported issues, verification records, records of processors, catches, marketplace information, and related media are all stored in MongoDB and/or media/cloud storage. The stored operational records can be used for Power

BI and spatial reporting analysis to provide reporting outputs of verified information, operational monitoring, dashboards, hotspot maps, and decision support insights. The generated output is available to each user based on their role within the system. For instance, stakeholders and fish hunters can view relevant analytical data and operational information; other users can view information related to their applications.

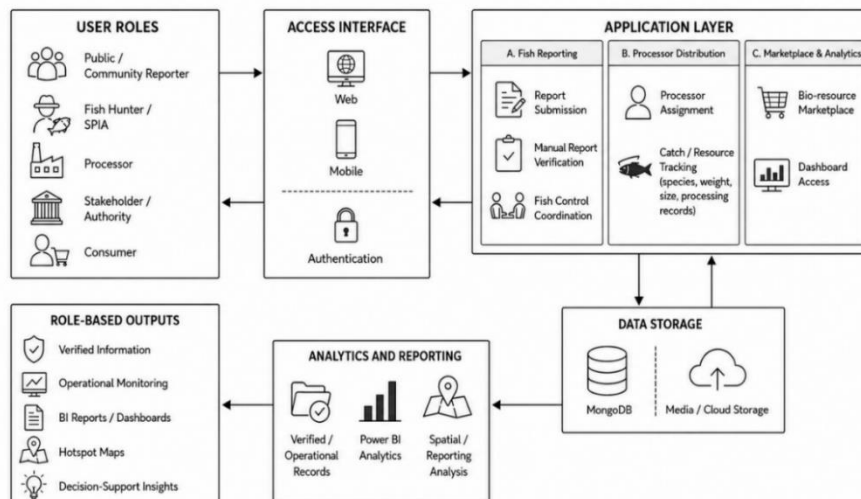


Fig 2. Proposed system architecture

4.2. Preliminary stakeholder evaluation

To obtain preliminary observations on the perceived operational suitability of the proposed conceptual workflow, two representatives of Skuad Pemburu Ikan Asing (SPIA) provided qualitative feedback following the prototype demonstration described in the methodology. The evaluation was intended to examine whether the integrated workflow broadly reflected current fish control practices and to identify potential implementation improvements prior to future deployment.

In essence, both stakeholders indicated that they perceived the proposed conceptual workflow as broadly reflecting the operational processes involved in invasive freshwater fish management and did not suggest major structural modifications to the framework. The feedback received primarily focused on implementation-level features of the working prototype, and specifically on technical functionalities, such as geospatial functions, notification mechanisms, processor allocation flexibility, marketplace integration, analytical dashboards, and usability. Stakeholder feedback was organized into recurring functional themes, which are presented in Table 1.

Table 1. Summary of preliminary stakeholder feedback

Features	Stakeholder Feedback
Geo-tagging location	The map positioning accuracy and geo-tagging precision can be improved for future deployment.
Notification alert	Automated notification mechanisms in mobile applications can be incorporated to improve communication between fish hunters and processors.
Processor distribution	Greater flexibility can be provided when assigning processors across operational regions where appropriate.
Marketplace integration	Integration with external e-commerce platforms could provide potential commercialization opportunities, especially for small businesses and processors.
Analytical dashboard	The Business Intelligence dashboards were perceived as providing richer monitoring for operational analysis and decision-support capabilities.
User interface	The interface terminology and navigation can be simplified to improve usability for stakeholders with limited technical familiarity.

Based on a preliminary stakeholder evaluation, the proposed framework was perceived by the participating stakeholders as broadly representing the current operational workflow, while

the evaluation also highlighted several refinements for future deployment. Notably, the recommendations focused on improving the prototype functionality rather than revising the

conceptual workflow, which suggests that the overall workflow was perceived by the two participating stakeholders as broadly in line with the current operational practice. Nevertheless, as this evaluation was exploratory and only two stakeholder representatives were involved, the results should be considered preliminary qualitative evidence for the refinement of the prototype and not as a formal validation of the system.

These findings suggest the preliminary potential of the proposed workflow to facilitate stakeholder coordination by employing an integrated operational approach to community-based reporting, processor distribution, and analytical environmental monitoring. Feedback from stakeholders regarding the analytical dashboard and the general workflow structure also suggests the potential value of these features for decision-support applications. Thus, these findings should not be interpreted as validation or acceptance by stakeholders of operational effectiveness, which can only be achieved through implementation and evaluation in real-world environments. The practical implications of these findings are discussed in the following sub-section on the Framework Impact.

4.3. Framework impact

Following the proposed framework described in the previous section, we present an integrated operational workflow for the management of invasive fish, combining three key processes, which are Fish Reporting, Processor Distribution, and Marketplace and Analytics. It integrates community reporting, control operations, resource processing, and analytical insights into a single digital workflow, in contrast to many current environmental monitoring projects that function in discrete stages. The lack of traceability, coordination, and decision-support capabilities across various stages of invasive species management are among the major limitations noted in earlier research which the proposed integration is intended to address (Unggang et al., 2023).

One of the main contributions of this framework lies in establishing a community-reporting data source for environmental monitoring rather than conventional methods. By using geotagged community reports and fish hunter verification, it is intended to improve the reliability of community-based reports (Leza et al., 2025) and could support the identification of new invasion hotspots through aggregated community reporting patterns, thereby potentially supporting more targeted fish control operations and reducing associated costs such as labour, fuel, and travel resources. The addition of traceability to the proposed bio-resource utilization process, which is intended to address a major operational gap in conventional fish control methods, represents a significant conceptual contribution.

Conventionally, captured invasive fish are most often disposed of by burying, as it is difficult to reach processors to distribute the caught fish. The proposed framework is designed to address this issue by assigning captured fish to registered processors while documenting their intended distribution and bio-resource processing pathways. This proposed traceability mechanism

would allow stakeholders to monitor the progression of captured biomass through planned conversion processes into useful products and is intended to improve transparency throughout the proposed capture-to-conversion chain. It could also support circular bio-resource economy initiatives by linking invasive fish management activities with opportunities for resource utilization.

The proposed framework is designed to support the transition from reactive monitoring to proactive ecosystem management by integrating analytics and business intelligence capabilities that facilitate the strategic planning of invasive fish control measures and resource allocation. It also highlights that its contribution does not derive from advanced individual technological components alone, but also from the integration of community engagement, traceability across proposed bio-resource conversion pathways, and analytical decision support into a unified platform, supporting coordinated invasive species management and sustainable ecosystem restoration strategies.

Existing environmental monitoring platforms have significantly improved biodiversity monitoring, geospatial visualization, and invasive species management. However, many platforms remain fragmented because they separate community-based reports from operational activities and bio-resource conversion (Engelstad et al., 2022). Additionally, recent studies have demonstrated the potential of digital platforms with AI-driven monitoring and digital twin technologies to improve predictive modelling and real-time environmental monitoring (Fricke & Olden, 2023; Ghosh & Kumar, 2026; Khan et al., 2024; Roy et al., 2024). Nevertheless, these studies focus only on environmental monitoring, such as habitat mapping and species tracking, rather than unifying invasive species control operations, processor coordination for bio-resource conversion, and ecosystem restoration planning in a single workflow.

Moreover, the practical operational bridge from community-based reporting to the implementation of the circular bioeconomy remains structurally limited. Despite many advances in digital innovations, current studies mostly operate as fragmented silos that fail to bridge the digital gap between data collection and operational implementation. As a result, most platforms rely on reactive responses, and efforts to bridge the practical gap from community-based reporting to circular bioeconomy implementation remain limited, thereby jeopardizing meaningful data-driven analysis for decision-making.

In contrast, the proposed framework addresses these limitations by integrating community-based reporting, fish control operations, processor distribution, proposed bio-resource conversion pathways, marketplace, and business intelligence analytics into a structured digital workflow. This integration bridges the gap between community-based fish sightings and the operational activities of stakeholders by systematically addressing the fragmentation of operations within the framework. Instead of introducing a monitoring algorithm or

predictive model, its contribution lies in connecting operational environmental monitoring with proposed bio-resource conversion pathways and ecosystem restoration initiatives. Hence, the proposed conceptual framework is intended to support coordinated decision-making by improving collaboration and providing conceptual guidance for bioeconomy initiatives through traceable operational workflows.

The proposed framework contributes to environmental management and has the potential to support ecosystem restoration and more informed management of invasive fish populations through community-based reporting data and descriptive reports. From an economic perspective, the proposed bio-resource conversion and marketplace modules provide conceptual pathways for potential utilization of captured invasive fish, which are typically regarded as ecological waste, as valuable bioresources, such as animal feed and fertilizers, subject to appropriate processing and future validation, and subsequently connect these potential outputs with potential market opportunities.

As regards social impact, the framework may encourage collaboration between stakeholders such as local communities, non-governmental organizations (NGOs), and fisheries agencies to promote community engagement in monitoring invasive species in the environment. Taken together, these proposed functions indicate the potential of the framework to provide support for the circular use of resources and sustainable aquaculture methods in freshwater ecosystems.

Next, the proposed framework further conceptualizes a feedback loop in which community-based fish reports, processing activities, and analytical insights continuously inform future decisions on ecosystem management. As such, these insights could support planning for the reintroduction of native fish into restored freshwater ecosystems when appropriate. This continuous loop of data, decision-making, and ecosystem restoration could ultimately support benefits to both communities and freshwater ecosystems, highlighting the value of integrated digital platforms for biodiversity restoration. In addition to integrating existing methods, the proposed framework emphasizes the combination of independent activities such as fish control, resource utilization, and analytics. It ties environmental challenges (i.e., invasive species) to potential economic opportunities and encourages the use of environmental data for informing management activities in the context of a unified operational workflow. Therefore, this illustrates how digital environmental management systems could support the development of sustainable agribusiness and biodiversity conservation.

In practical terms, the proposed framework provides an organizational reference to help modernize the management of invasive freshwater fish by means of digital applications. Instead of fragmented technological functionalities, the framework provides a flexible, practical implementation guide for the development of integrated environmental information

systems. It allows practitioners to devise implementation strategies integrating community engagement, operational management, bio-resource utilization, and analytical decision-making in support of environmental management initiatives. Hence, the framework may assist many stakeholders in planning future digital implementations by minimizing operational fragmentation and improving information sharing between organizations.

Meanwhile, from a theoretical perspective, this study contributes to the environmental information systems literature by proposing a unified conceptual model that integrates environmental monitoring with proposed circular bioeconomy processes. Moreover, existing studies tend to treat environmental monitoring, bio-resource utilization, and decision-making as distinct areas of research. In contrast, the proposed framework conceptualizes these areas as integral components of the continuous cycle of the operational ecosystem. This combined perspective extends the current conceptualization of environmental information systems by placing operational integration as a guiding principle for design, rather than emphasizing individual technological innovation. Thus, the proposed framework provides a conceptual foundation for future empirical validation, cross-domain adaptation, and the development of integrated environmental management.

4.4. Limitations

The study acknowledges several significant limitations. The proposed conceptual framework has not been implemented in real-world settings and has not been subject to any quantitative validation. Therefore, key indicators such as operational performance, reporting efficiency, processing traceability, and usability could not be empirically assessed. Moreover, the main focus of the study is to demonstrate the conceptual integration workflow of the three components proposed, rather than to validate the technological performance separately.

Specifically, in this study, the proposed bio-resource conversion pathways and the final products have not been assessed experimentally; thus, their technical, environmental, and economic feasibility remains to be evaluated. However, the framework provides a systematic basis for future implementation as well as empirical testing of operational performance for more comprehensive quantitative evaluations in the context of environmental management and the circular economy. Furthermore, the study included only two representatives of SPIA as a preliminary assessment of the stakeholders. These qualitative results should therefore be interpreted as exploratory findings intended to provide iterative improvements to the prototype and not as generalizable evidence of stakeholder acceptance. Consequently, these limitations must be considered when interpreting the findings, as the present study seeks to establish and refine a conceptual foundation rather than provide conclusive empirical evidence.

The stakeholder evidence is also limited by the small sample size and the specific operational environment of SPIA in

Malaysia. As such, these limitations could restrict the applicability of this study to other geographic areas or organizations. Additionally, as two of the SPIA representatives involved in the stakeholder activity served as co-authors of the study, there is a potential for researcher-participant bias. Therefore, this potential bias should be considered when interpreting the preliminary stakeholder findings. A standardized usability instrument was not utilized to evaluate the prototype and, therefore, no formal usability metrics were developed. In addition, the qualitative data collected during the study was not independently coded by multiple researchers. Consequently, inter-coder reliability was not established in this study.

5. Conclusions and Future Work

In conclusion, this paper presents a conceptual framework for managing invasive fish species through integrated operations, consisting of three core processes: Fish Reporting, Processor Distribution, and Marketplace and Analytics. It aims to facilitate targeted control operations, traceability across the proposed bio-resource conversion pathways, and analytical insights for ecosystem management. The framework shows how community-generated geotagged reports can be transformed into a closed-loop operational cycle, enabling proposed processing and distribution traceability and visual analytics insights to address the fragmented operations of current conventional methods. This framework is designed to support invasive freshwater fish control, bio-resource utilization, ecological waste monitoring, and informed decision-making by integrating these operational processes into a single workflow.

Therefore, the integration of operational traceability, community engagement, and analytical decision support illustrates how an integrated conceptual framework of digital platforms may facilitate more sustainable and coordinated environmental management strategies for invasive freshwater fish control. Each of the three core processes within the framework collectively aligns with SDG 14, Life below Water, by protecting the biodiversity of native fish while addressing the threat of invasive species and providing potential pathways for bio-resource utilization through systematic fish control and proposed processor distribution. The proposed framework is also aligned with SDG 12, Responsible Consumption and Production, and SDG 8, Decent Work and Economic Growth, through the proposed bio-resource conversion pathways and potential circular economy practices within freshwater resource management.

Future work will focus on improving community-report surveillance, report verification, monitoring scalability, and integrating machine learning-based image classification to enable automated identification of invasive fish species from submitted images. A broader user evaluation will be carried out in nearby areas in a real-world environmental setting to test the robustness of the prototype. Additionally, future validation will involve quantitatively assessing reporting efficiency,

traceability across the proposed bio-resource conversion pathways, stakeholder usability, and overall operational performance using data collected during pilot implementation. The study will also evaluate the practical feasibility of the framework, the reliability of reporting processes, processing traceability, dashboard usability, and its effectiveness in supporting ecosystem management decision-making. Future research should experimentally assess the technical feasibility and performance of the proposed bio-resource conversion pathways and their resulting products.

Acknowledgments

The authors would like to thank the Center for Advanced Computing Technology (C-ACT), Fakulti Teknologi Maklumat dan Komunikasi (FTMK), Universiti Teknikal Malaysia Melaka (UTeM), for their support and facilities during this research study. This study is sponsored by research grant PJP/2024/FTMK/PERINTIS/SA0044.

Statement and Declarations

Data availability

Qualitative data was generated but is not publicly available due to participant confidentiality and privacy considerations. Aggregated findings relevant to the study are reported in the manuscript.

Conflict of interest

The authors declare no conflict of interest regarding the authorship or publication of this paper.

Author contributions

The authors contributed to the study through conceptualization, framework development, operational domain input, stakeholder consultation, analysis, and manuscript preparation according to their respective roles. All authors reviewed and approved the final manuscript.

Declarations

Artificial Intelligence (AI)-assisted tools were used in this paper to improve language clarity, proofreading, literature search, and editing during manuscript preparation. However, all research content, ideas, conceptual designs and interpretations were the responsibility of the authors.

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