International Journal of Entrepreneurship and Management Practices
IJEMP
EISSN : 2600-8750

Volume 7 Issue 28 (December 2024) PP. 13-29
DOI: 10.35631/IJEMP.728002

INTERNATIONAL JOURNAL OF ENTREPRENEURSHIP AND MANAGEMENT PRACTICES (IJEMP)
www.ijemp.com

GLOBAL ACADEMIC EXCELLENCE

A SIGNIFICANT STRUCTURE REVIEW: DEEP POOLS AND FISH SPAWNING HABITAT IN FISHERIES MANAGEMENT

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Article Info:

Article history:
Received date: 27.09.2024
Revised date: 09.10.2024
Accepted date: 05.11.2024
Published date: 17.12.2024

To cite this document:

Ak-Slat, S., Abdullah, N. M., & Yatim, M. H. M. (2024). A Significant Structure Review: Deep Pools And Fish Spawning Habitat In Fisheries Management. *International Journal of Entrepreneurship and Management Practices*, *7* (28), 13-29.

DOI: 10.35631/IJEMP.728002.

Abstract:

The sustainability of fisheries is intricately linked to the conservation of critical habitats, particularly deep pools that serve as vital fish spawning grounds. This systematic literature review aims to explore the significance of deep pools in the reproductive success and management of fish populations. The study identifies critical challenges in fisheries management, including habitat loss, environmental changes, and the need for targeted conservation efforts. To address these challenges, a comprehensive search and analysis of peer-reviewed articles from databases such as Scopus and Web of Science was conducted, focusing on research published between 2022 and 2024. The methodology followed PRISMA guidelines to ensure a rigorous selection process, resulting in 40 high-quality studies being included in the final review. The findings were divided into three themes: (1) fisheries management and conservation, (2) environmental impact on fisheries, and (3) methodological approaches in fisheries research. The findings highlight the crucial role of deep pools in supporting fish spawning, with evidence showing that these habitats contribute significantly to the maintenance and enhancement of fish stocks. Results indicate that well-managed deep pools can lead to an increase in fish population densities, underscoring their importance in fisheries management. However, the review also needs to identify gaps in the current understanding of the complex interactions between fish species and their spawning habitats. The conclusion emphasizes the necessity for integrated management strategies that prioritize the protection of deep pools to ensure the long-term sustainability of global fisheries.

Keywords:

Deep Pools, Hotspot, Fish Spawning Habitat, Fisheries Management

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DOI: 10.35631/IJEMP.728002

Introduction

The current issue in fisheries management revolves around the protection and enhancement of critical habitats, particularly deep pools and spawning areas, which are essential for the sustainability of fish populations. Ecosystem sustainability of healthy fish populations requires effective fisheries management that is influenced by the ecological factors of deep pools, or fish hotspots. A deep pool is characterized by a deep depth compared to the surrounding area. This factor is at the centre of discussion for sustainable fisheries management because it affects fish spawning and the early stages of fish life (Espinoza et al., 2022). Deep pools offer nursery habitat and protection of fish eggs and fry from solid currents, extreme temperatures and predators, creating a safe microhabitat. For example, during the spawning period, deep pools successfully breed fish because the eggs are less exposed to disturbance from sediments and strong currents, which are essential for the survival of the developing embryos (Ahmed et al., 2022). The complexity of juvenile fish environments at varying depths and substrates offers abundant food sources and protection from predators. In this way, deep pools support both reproductive and early development stages and contribute to the overall health and resilience of the fish population.

Deep pools are important and vital for fish habitat, especially juvenile fish, due to significant threats from human activities such as road river crossing, dam construction, water diversion and channel modification. Such actions disrupt natural river dynamics, leading to the deterioration of deep pools and affecting fish populations. Therefore, the integration of deep pools conservation into a broader fisheries management strategy able to protect existing deep pools, restore degraded pools, as well as management practices that consider the dynamic nature of river ecosystems, by integrating knowledge of spatial and temporal management, hydrology, fish habitat needs and human influence (Acreman et al., 2020; Dejen et al., 2017; Thieme et al., 2023). Adaptive management strategies to changing environmental conditions incorporate monitoring data to address threats to maintaining the ecological health of deep pools, maintaining good quality natural water flows, and establishing natural depth profiles so that fish habitat connectivity is always well maintained. In conclusion, marine or inland fisheries in deep pools fish habitat requires proactive, collaborative and well-informed adaptive management strategy and practices by focusing on the protection and restoration of deep pools, the resilience of fish populations will increase and contribute to long-term sustainability to address the challenges posed by human activities.

Literature Review

Deep pools are often located in river systems and serve as crucial spawning and juvenile development areas for many fish species. The fisheries industry relies on the health and accessibility of these habitats to sustain fish populations and, consequently, the economic viability of fishing operations. Creating a fish spawning habitat environment at a specific sub-composition, temperature and depth is essential in fisheries management. Fish prefer deep pools at specific depths and velocities during spawning. Deep pools are essential spawning habitats for many fish species, including Arctic char (*Salvelinus alpinus*), brook trout (*Salvelinus fontinalis*), and sauger (*Sander canadensis*). Identified deep pools fed by groundwater characterized by depths greater than 2 meters and stable temperature regimes, offer refuge from freezing during winter and provide a stable environment for eggs and larvae during the spawning season (Harwood & Babaluk, 2014). This is supported by the study in the Nanxi River, which showed that deep pools and riffles can support fish during spawning and migration periods (Kupferschmidt et al., 2019). The interaction between habitat characteristics and parasite communities at different depths, which will affect the dynamics of the parasite

EISSN : 2600-8750
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community and, in turn, affect reproductive success and fish health (Siwertsson et al., 2016). Gulf sturgeon (*Acipenser oxyrinchus desotoi*), Gila fish (*Salmo gilae*) and Arctic char (*Salvelinus alpinus*) select suitable spawning habitat sites with gravel or rock substrates, specific water depths and range of pH and calcium ions, which are essential for overwintering and survival reproductive success (Beddow et al., 1998; Rinne, 1980; Sulak & Clugston, 1999).

The assessment of the effectiveness of constructed wood jams in creating deep pools and enhancing habitat quality for salmonids in Pacific Northwest streams found that complex wood jams significantly increased pool covers and habitat heterogeneity, improving conditions for spawning and juvenile development. This complex wood jam highlights the potential of restoration techniques to enhance deep pool habitats and support fish populations (Flannery et al., 2017). In contrast, Silver Shiners in an urbanized river fragment has been focused, where habitat degradation affected spawning and habitat use (Bunt, 2016). Despite the challenges, the study observed that Silver Shiners utilized pools near groundwater seepages, emphasizing the need for targeted habitat management to maintain critical spawning sites in altered environments. Degradation of pool habitats due to sedimentation and dam construction affects fish populations and damages spawning habitats. Therefore, habitat suitability modelling showed that the CU index better describes spawning habitat quality than traditional substrate metrics (Beecher et al., 2024). This suggests that combining deep pools and unit channels improves habitat suitability prediction (Al-Shaer et al., 2018). Studies have been conducted to assess spawning habitat quality by developing a coastal complexity index that incorporates slope and vegetation coverage and the identification of path barriers to fish migration movements. Their study provide a framework to assess habitat quality through the development of a coastal complexity index (CCI) that combines slope coverage and vegetation to assess fish spawning habitat as well as developing fish passage models to identify barriers to fish migration, emphasizing how habitat features such as deep pools can positively impact fish movement and spawning (Deng et al., 2022; Mao et al., 2023; Meixler, 2021).

In conclusion, comprehensive management strategies in deep pools or fish hotspot areas are vital for refuge areas and fish spawning. Advances in knowledge and technology in habitat modelling, restoration techniques, and understanding of ecological interactions contribute to more effective fisheries management and habitat conservation.

Methodology

The methodology employed in this study is guided by PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). This approach is a widely recognized standard for conducting systematic literature reviews, ensuring transparency, completeness, and consistency throughout the process. By following PRISMA guidelines, authors are guided to systematically identify, screen, and include studies in their review, which enhances the accuracy and rigor of the analysis. The approach also emphasizes the importance of randomized studies, recognizing their value in reducing bias and contributing robust evidence to the review. In this analysis, two key databases, Scopus and Web of Science, were utilized due to their robust nature and extensive coverage. Both Scopus and Web of Science offer a comprehensive index of peer-reviewed literature across various disciplines. However, it is acknowledged that no database is perfect; each has its limitations, such as coverage gaps or varying levels of detail, which must be considered during the review process.

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The PRISMA approach is further structured into four significant sub-sections: identification, screening, eligibility, and data abstraction. As shown in Figure 1, identification involves searching databases to find all relevant studies, followed by screening, where studies are assessed against predefined criteria to exclude irrelevant or low-quality research. The eligibility phase further evaluates the remaining studies to ensure they meet the criteria for inclusion. Finally, data abstraction involves extracting and synthesizing data from the included studies, which is crucial for drawing meaningful and reliable conclusions. This structured approach ensures that the systematic review is conducted with high rigor, producing reliable results that can inform further research and practice.

Formulation Of Review Questions

The formulation of review questions is crucial because it guides the authors in progressing throughout the SLR, particularly in processes such as identification, screening, quality appraisal, data extraction, and report development (Haddaway, N. R., Macura, B., Whaley, P., & Pullin, 2018; Lockwood, C., Munn, Z., & Porritt, 2015; Mohamed Shaffril et al., 2021). Furthermore, a well-defined review question aids readers in determining whether the review addresses their information needs (Lockwood, C., Munn, Z., & Porritt, 2015). To formulate the review questions, the authors utilized PICo (Population, Interest, Context), a mnemonic often employed in systematic reviews, to craft questions for qualitative synthesis.

1. How do protected areas influence the reproductive success and population stability of fish species that rely on spawning aggregations in identified hotspot regions?
   Population: Fish species that form spawning aggregations
   Interest: The effectiveness of protected areas in conserving fish populations and enhancing reproductive success.
   Context: Fisheries management strategies in regions with known fish spawning hotspots.
2. How can spatial modelling techniques identify and manage fish spawning hotspots in ecologically sensitive fisheries?

   Population: Commercially important fish species
   Interest: The impact of climate change and environmental variability on fish spawning habitats and recruitment success
   Context: Ecologically sensitive fisheries
3. How can advanced spatial and modelling techniques be optimized to identify and manage fish spawning hotspots in data-limited and ecologically sensitive fisheries?

   Population: Marine species being monitored or managed through technological interventions.
   Interest: The use of advanced technological tools and models in fisheries management.
   Context: Data-limited and ecologically sensitive fisheries.

These review questions are designed to guide further investigation into key areas of fisheries management, environmental impacts, and methodological approaches, each focusing on critical aspects of conserving and managing fish populations in spawning habitats.Systematic searching strategies.

International Journal of Entrepreneurship and Management Practices
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IJEMP
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The formulation of the research question preceded the execution of systematic search strategies. This stage involved three essential procedures: identification, screening, and assessment of eligibility. Such a methodical approach guarantees that the review captures a thorough search process.

Identification

This research adopted essential phases of the systematic review methodology to collect significant literature relevant to the subject. The initial step involved selecting keywords and exploring associated terms using dictionaries, thesauri, encyclopaedias, and existing studies. According to Table 1, relevant terms were identified, subsequently leading to the development of search strings for utilization in the Scopus and Web of Science databases. As a result of this preliminary phase of the systematic review, a total of 528 publications related to the topic under investigation were obtained from these two databases

Table 1: The Search String

Scopus	TITLE-ABS-KEY (("deep pool" OR "deeps pool" OR "deep pools" OR "deeps pools" OR "hot* spot" OR "hot spot" OR hotspot OR "fish* spawn*") AND ("fish* manage*")) AND (LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2023) OR LIMIT-TO (PUBYEAR , 2024)) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (SUBJAREA , "ENVI") OR LIMIT-TO (SUBJAREA , "SOCI")) **Date of Access: August 2024**
WoS	TS= (("deep pool" OR "deeps pool" OR "deep pools" OR "deeps pools" OR "hot* spot" OR "hot spot" OR hotspot OR "fish* spawn*") AND (“fish* manage*")) and Article (Document Types) and 2024 or 2023 or 2022 (Publication Years) **Date of Access: August 2024**

Source: Authors (2024)

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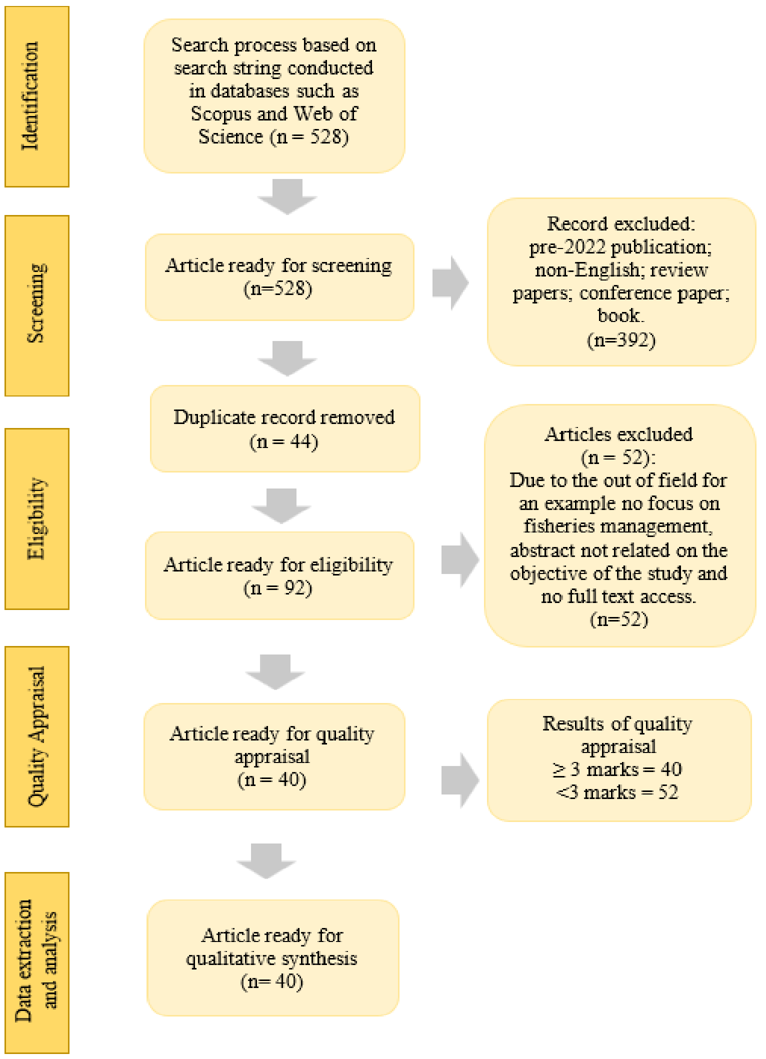

Figure 1. Systematic Searching Strategy

Screening

The represented the second stage of the systematic searching strategy, wherein the initial collection of 528 articles was critically assessed for their appropriateness to be included in the review. The first criterion considered was the publication period, specifically focusing on works released between 2022 and 2024. Consequently, the examination of the selected databases for articles from this timeframe proved fruitful, enhancing the selection of the most relevant studies for the review. The second criterion addressed the type of publication, with a specific focus on including only journal (Linares-Espinós, E., Hernández, V., Domínguez-Escrig, J. L., Fernández-Pello, S., Hevia, V., Mayor, J., ... & Ribal, 2018). Journal articles typically undergo a thorough peer-review process, ensuring a higher standard of quality, which supports the quest for credible content. Furthermore, the third criterion required that the articles must provide primary data, excluding review or secondary data sources. The language of the publications was also a consideration; only articles published in English were included. Following the application of these criteria and the elimination of 44 duplicate entries, a total of 436 articles were excluded, leading to 92 articles being identified as appropriate for advancement to the eligibility phase.

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Eligibility

At this phase, a re-evaluation of all selected articles was performed to ensure their relevance according to the inclusion criteria established for the study, aimed at addressing all review questions. The screening involved a careful examination of the titles and abstracts of the articles, with additional scrutiny of the methodology sections when deemed necessary. Through this process, a total of 52 articles were eliminated because they did not sufficiently concentrate on fisheries management. Furthermore, several articles did not specifically pertain to fish spawning habitats. As a result of this thorough examination, 40 articles were identified as eligible for the subsequent quality appraisal

Quality Appraisal

The 40 articles for the quality appraisal stage were essential for reducing bias and maintaining the quality and reliability of the chosen works (Haddaway, N. R., Macura, B., Whaley, P., & Pullin, 2018; Mohamed Shaffril et al., 2021).). The quality review was conducted through a collaborative discussion among the authors, taking place over two sessions. Initially, all selected articles were read, followed by a discussion focused on their quality. For this study, the quality assessment framework provided by Abouzahra et al. was applied, comprising six evaluative questions designed for the systematic literature review. These questions are as follows: (1) Is the study's purpose clearly stated?; (2) Are the significance and relevance of the work clearly articulated?; (3) Is the methodology of the study clearly outlined?; (4) Are the concepts within the approach clearly defined?; (5) Is there a comparison with other similar works?; and (6) Are the limitations of the study clearly acknowledged? (Abouzahra et al., 2020). The assessment of each criterion is rated using three possible values: "Yes" (Y), scoring 1 if fully met; "Partially" (P), scoring 0.5 if somewhat met but containing gaps; and "No" (N), scoring 0 if not met at all. To qualify for the subsequent phase, a total score exceeding 3.0 is required. This criterion guarantees that only studies that achieve a specific quality standard move forward in the process.

Data extraction and Analysis

An analysis was employed as a key assessment method in this research to investigate and synthesize diverse research designs, particularly quantitative approaches. The primary aim of this analysis was to identify pertinent topics and subtopics. The data collection phase represented the initial step in developing thematic categories. Afterward, a review of significant studies linked to fisheries management was conducted. This involved a thorough examination of the methodologies applied across all studies, as well as their respective research findings. Subsequently, collaboration with co-authors took place to establish themes grounded in the evidence collected within the study's framework. Throughout the data analysis process, a log was maintained to document analyses, perspectives, inquiries, or any other relevant thoughts concerning data interpretation. In the final stage, the established themes were refined to enhance their coherence. To validate the identified issues, evaluations were conducted by three experts, consisting of one specializing in fisheries governance and two with expertise in institutional analysis, development frameworks, and fisheries management practices. This expert review phase aimed to ensure clarity, significance, and adequacy within each sub-theme, thereby confirming domain validity. Adjustments were made based on the authors' discretion, incorporating insights and comments from the experts.

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Research Findings

As shown in Table 2 the authors show a compilation of 40 publications for assertions or material relevant to the topics of the current study.

Table 2: Background of Selected Articles

No.	Title and Author(s)	Source title	Scopus	WoS
1	Integrating fish nursery ground conservation with sustainable resource use: The case of Trichiurus japonicus in the East China Sea (Jin et al., 2024)	Aquatic Conservation: Marine and Freshwater Ecosystems	/	
2	Operationalizing a fisheries social-ecological system through a Bayesian belief network reveals hotspots for its adaptive capacity in the southern North sea (Kruse et al., 2024)	Journal of Environmental Management	/	
3	Spatial information extraction of fishing grounds for light purse seine vessels in the Northwest Pacific Ocean based on AIS data (Wan et al., 2024)	Heliyon	/	/
4	Identifying priority areas for spatial management of mixed fisheries using ensemble of multi-species distribution models (Panzeri, Russo, et al., 2024)	Fish and Fisheries	/	
5	Incorporating climate-readiness into fisheries management strategies (Talbot et al., 2024)	Science of the Total Environment	/	
6	Future distribution of demersal species in a warming Mediterranean sub-basin (Panzeri, Reale, et al., 2024)	Frontiers in Marine Science	/	/
7	Nutritional quality of eastern school whiting (Sillago flindersi) under contemporary and future environmental conditions (Shalders et al., 2024)	Fisheries Oceanography	/	
8	A hotspot and mechanism of enhanced bottom intrusion on the southern New England shelf (K. Chen, 2024)	Environmental Research Communications	/	/
9	Diversity, challenges, and opportunities of Fishery Improvement Projects in the Latin America and the Caribbean region (Gomez-Gomez et al., 2024)	Marine Policy	/	/
10	Biodiversity and Conservation of Fish in the Beibu Gulf (Teng et al., 2024)	Pakistan Journal of Zoology	/	
11	Fishing profile and commercial landings of shark and batoids in a global elasmobranchs conservation hotspot (Lutz et al., 2024)	Anais da Academia Brasileira de Ciencias	/	/
12	Population dynamics of spotted scat, Scatophagus argus (Linnaeus 1766) from the Sundarbans of Bangladesh (Sakib et al., 2024)	Heliyon	/	/
13	Geolocated fish spawning habitats (Oremus et al., 2024)	Scientific Data		/
14	A stakeholder-engaged approach to evaluating spawning aggregation management as a strategy for conserving bonefish (Albula vulpes) in Cuba (Ostrega et al., 2023)	Environmental Biology of Fishes	/	/
15	Modelling drivers of trawl fisheries discards using Bayesian spatio-temporal models (Soto et al., 2023)	Fisheries Research	/	

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16	Evaluating Suitability of Fishing Areas for Squid-Jigging Vessels in the Northwest Pacific Ocean Derived from AIS Data (Fei et al., 2023)	Fishes	/	/
17	The influence of temperature on Pacific hake co-occurrence with euphausiids in the California Current Ecosystem (Phillips et al., 2023)	Fisheries Oceanography	/	
18	Protected fish spawning aggregations as self-replenishing reservoirs for regional recovery (Stock et al., 2023)	Proceedings of the Royal Society B: Biological Sciences	/	/
19	Analysis of fish migration in correspondence with wood and rock-made instream structures (Kurdistani et al., 2023)	Geomorphology	/	
20	Acoustic telemetry provides insights for improving conservation and management at a spawning aggregation site of the endangered Nassau grouper (Epinephelus striatus) (Nemeth et al., 2023)	Frontiers in Marine Science	/	
21	Sensitivity of fishery resources to climate change in the warm-temperate Southwest Atlantic Ocean (Gianelli et al., 2023)	Regional Environmental Change	/	/
22	Population structure of commercially important groupers in the coral triangle Gorontalo, Indonesia to support conservation (Achmad et al., 2023)	Biodiversitas	/	/
23	Cage farming in the environmental mix of Lake Victoria: An analysis of its status, potential environmental and ecological effects, and a call for sustainability (Nyakeya et al., 2023)	Aquatic Ecosystem Health and Management	/	
24	Blue shark (Prionace glauca) occurrence and relative abundance in the western South Atlantic Ocean influenced by spatiotemporal variability, environmental variables, and oceanographic processes (Rondon-Medicci et al., 2023)	Marine Environmental Research	/	
25	Conservation benefits of no-take marine reserves outweigh modest benefits of partially protected areas for targeted coral reef fishes (Hall et al., 2023)	Coral Reefs	/	
26	Revealing the Current Situation and Strategies of Marine Ranching Development in China Based on Knowledge Graphs (Y.-H. Chen et al., 2023)	Water (Switzerland)	/	
27	Feeding after spawning and energy balance at spawning are associated with repeat spawning interval in steelhead trout (Jenkins et al., 2023)	General and Comparative Endocrinology	/	/
28	Genomic analyses indicate resilience of a commercially and culturally important marine gastropod snail to climate change (Nimbs et al., 2023)	PeerJ	/	/
29	A study of the hydraulic parameters and ecological significance of braided rivers under flow variations (H. Wang et al., 2022)	River Research and Applications	/	
30	Spatio-temporal dynamics of fish assemblage in the Datong and Xiaotong rivers, karst tributaries in the upper Yangtze River drainage: Implications for ecological adaptation and conservation of fish in rivers (Xiang et al., 2022)	Frontiers in Ecology and Evolution	/	/
31	Direct evidence of a spawning aggregation of cubera snapper (Lutjanus cyanopterus) in southeastern Brazil and its management implications (Motta et al., 2022)	Fisheries Research	/	/
32	Identifying persistent biomass areas: The case study of the common sole in the northern Iberian waters (Pennino et al., 2022)	Fisheries Research	/	
33	Hotspot Habitat Modeling of Skipjack Tuna (Katsuwonus pelamis) in the Indian Ocean by Using Multisatellite Remote Sensing (Vayghan & Lee, 2022)	Turkish Journal of Fisheries and Aquatic Sciences	/	/

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34	Where do recruits come from? Backward Lagrangian simulation for the deep water rose shrimps in the Central Mediterranean Sea (Gargano et al., 2022)	Fisheries Oceanography	/	/
35	Demographic Recovery of a Reef Fish Population Over 30 Years of Spawning Aggregation Site Protection (Rosemond et al., 2022)	Frontiers in Marine Science	/	/
36	Song recordings suggest feeding ground sharing in Southern Hemisphere humpback whales (Schall et al., 2022)	Scientific Reports	/	
37	Mangroves and the Sustainability of Longtail Shad Fish (Tenualosa macroura) in Riau Province Water, Indonesia (Seygita et al., 2022)	International Journal on Advanced Science, Engineering and Information Technology	/	
38	Multi-species hotspots detection using self-organizing maps: Simulation and application to purse seine tuna fisheries management (Stephan et al., 2022)	Methods in Ecology and Evolution	/	/
39	Advances in the use of nighttime light data to monitor and assess coastal fisheries under the impacts of human activities and climate and environmental changes: A case study in the Beibu Gulf (Tian et al., 2022)	Marine Policy	/	
40	The life history of longnose emperors (Lethrinus olivaceus) and a data-limited assessment of their stock to support fisheries management at Rangiroa Atoll, French Polynesia (Filous et al., 2022)	Journal of Fish Biology		/

Source: Authors (2024)

Result and Finding

Fisheries Management and Conservation

Fish spawning aggregations are vital for many species, serving as key locations where fish gather to reproduce, which also makes them susceptible to overfishing. In Cuba, for example, the bonefish (*Albula spp.*) population is threatened due to a lack of specific management strategies. Incorporating local ecological knowledge and involving various stakeholders in managing these spawning sites has shown to be beneficial. Using marine protected areas (MPAs) and enforcing regulations on timing and location is crucial for the effective management of these vital habitats (Ostrega et al., 2023). Similarly, the Nassau grouper (*Epinephelus striatus*) has experienced significant decline due to the targeting of its spawning sites. The combination of MPAs and biophysical modeling to understand larval dispersal is critical for recovery efforts, especially in areas like Little Cayman where local retention of larvae is imperative (Stock et al., 2023). However, Brazil faces challenges with the cubera snapper (*Lutjanus cyanopterus*), as existing legislation does not effectively consider scientific research on their spawning timing, highlighting the need for strategies informed by environmental dynamics (Motta et al., 2022). The establishment of the Red Hind Bank Marine Conservation District (MCD) has shown improvement in the red hind (*Epinephelus guttatus*) population, demonstrating that well-enforced MPAs can support recovery from overexploitation (Rosemond et al., 2022).

Environmental factors, such as temperature and salinity, critically determine the suitability of spawning habitats for various fish species. The hairtail (*Trichiurus japonicus*) in the East China Sea faces overfishing, with seasonal changes affecting its nursery grounds. This overlap with fishing activity necessitates tailored management approaches to lessen the impact on these

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essential habitats (Botha, 2023). The importance of environmental conditions is further illustrated in the US Virgin Islands' Nassau grouper spawning aggregations, where expanding the size and duration of MPAs could enhance protection during spawning periods. Local and traditional knowledge integration with scientific data has proven effective for managing fish habitats, as noted in Cuba's bonefish management efforts (Ostrega et al., 2023). Similarly, the longnose emperor (*Lethrinus olivaceus*) management in the Pacific Islands showcases how community practices alongside scientific studies contribute to conservation efforts (Gomez-Gomez et al., 2024). MPAs have emerged as effective strategies for conserving fish spawning locations and ensuring fishery sustainability, with fully protected zones demonstrating significantly higher fish biomasses compared to unprotected waters, underscoring their role in enhancing marine resilience (Achmad et al., 2023; Hall et al., 2023). In conclusion, protecting fish spawning aggregations is essential because many species are vulnerable during their reproductive periods. Effective management of these sites requires incorporating local knowledge and employing marine protected areas to sustain fish populations. Challenges in fisheries management underscore the need for adaptive strategies based on scientific research. Environmental factors significantly influence spawning habitat selection, necessitating management approaches tailored to fishing fleets. Combining local and traditional knowledge with scientific research is crucial for successful fisheries management. Marine protected areas play an important role in conserving fish populations and strengthening marine ecosystem resilience, highlighting their significance in sustainable fisheries management.

Environmental Impact on Fisheries

Ocean temperature significantly affects predator-prey relationships, species distribution, and overall ecosystem dynamics, making it essential to consider the influence of climate change. In the California Current Ecosystem, the co-occurrence of Pacific hake with krill is stronger during cooler temperatures, which impacts their growth and recruitment (Phillips et al., 2023). Similarly, in the Southwestern Atlantic Ocean, mollusks and chondrichthyans show vulnerability to warming waters, emphasizing the necessity for adaptive management strategies to address these changes (Gianelli et al., 2023). Climate change poses risks to fish stocks in various regions, such as the Philippines, where rising ocean temperatures may decrease pelagic species, threatening food security for coastal communities (Talbot et al., 2024). Concerns also arise in the Adriatic and Western Ionian Seas, where species are shifting northward, indicating the need for long-term management considering environmental changes (Panzeri, Russo, et al., 2024). Additionally, in Lake Victoria, ecosystem degradation due to overfishing and pollution has harmed fisheries, and while cage culture may offer some solutions, it requires careful management to mitigate negative ecological impacts (Nyakeya et al., 2023). The poleward shift of species like the turban snail in Southeastern Australia due to rising temperatures also presents challenges for fisheries management, highlighting the importance of understanding species adaptability to inform proactive strategies (Nimbs et al., 2023).

Methodological Approaches in Fisheries Research

Spatial fisheries management necessitates a thorough understanding of how target species and discards are distributed. Utilizing Bayesian hierarchical spatio-temporal Gamma regression models can provide valuable insights into the factors influencing discarding practices, combining various metrics such as Total Discards, Discards Per Unit of Effort, and Total Discard Ratio. This approach allows for a detailed evaluation of the ecological effects of discarding and helps pinpoint areas with high discard rates, making spatial maps a useful tool for managing fisheries effectively (Soto et al., 2023). Additionally, studies employing hydrodynamic modeling in river systems, like the Yarlung Tsangpo River, demonstrate how

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varied hydraulic parameters in branching channels can enhance the quality of spawning habitats. These models indicate that stable flow regimes are crucial for maintaining optimal nursery conditions for fish, underscoring their importance in protecting habitats in braided river ecosystems (Y. Wang et al., 2023). Habitat Suitability Index (HSI) models, implemented using methods like the weighted arithmetic mean and Boosted Regression Trees, improve the understanding of spatial and temporal fishing activity distribution, as seen in squid-jigging practices in the Northwest Pacific (Soto et al., 2023).

Research assessing the spatio-temporal dynamics of fish communities in rivers, such as the Datong and Xiaotong rivers, highlights the significance of habitat diversity for fish population stability. The absence of distinct temporal patterns in fish assemblages, linked to short migrations and various mesohabitats, denotes the necessity for targeted conservation efforts in specific river sections (Xiang et al., 2022). Further studies on adult common sole in the Northern Atlantic Iberian waters using Bayesian methods reveal critical patterns in distribution that inform fisheries management. By identifying abundance hotspots and their correlation with environmental factors, better management strategies can be developed (Pennino et al., 2022). Remote sensing and Lagrangian dispersion models also improve fisheries management precision, as illustrated by the integration of Automatic Identification System (AIS) data and spatial analysis approaches in the Northwest Pacific (Wan et al., 2024). The application of self-organizing maps (SOMs) for analyzing multispecies fisheries data promotes visualization of complex datasets and identification of catch hotspots, providing scientific support for decision-making in sustainable fisheries management (Gargano et al., 2022). In summary, spatial modelling and Bayesian approaches play a crucial role in fisheries management by providing a comprehensive understanding of discarding practices and identifying ecological impacts. Hydrodynamic modelling and habitat suitability indexes help in optimizing fish-spawning habitats and managing fishing pressure. Ecological assessments reveal the importance of habitat diversity in sustaining fish populations, while remote sensing and Lagrangian dispersion models enhance precision in monitoring fishing activities. Self-organizing maps offer a novel method for visualizing fisheries data and identifying catch hotspots for sustainable practices across different fisheries systems.

Discussion and Conclusion

Protecting fish spawning aggregations is essential due to the heightened vulnerability of species during these critical reproductive periods. Effective management of these sites requires the integration of local ecological knowledge and the implementation of marine protected areas (MPAs). Adaptive strategies, informed by scientific research, are necessary to address the challenges in fisheries management, particularly those related to environmental factors that influence spawning habitat selection. The success of these strategies depends on their ability to incorporate local and traditional knowledge, which has proven valuable in several case studies. MPAs, when properly enforced, play a crucial role in conserving fish populations and enhancing the resilience of marine ecosystems, making them a key component of sustainable fisheries management (Abdullah et al., 2016). The influence of temperature on species distribution and co-occurrence plays a vital role in understanding the broader implications of climate change on marine ecosystems. In regions like the California Current Ecosystem and the Southwestern Atlantic Ocean, temperature variations are altering the spatial distribution and interaction of species, such as Pacific hake and krill. These changes affect not only their ecological roles but also their availability to fisheries. Similarly, in the Philippines, the projected decline in pelagic species due to rising ocean temperatures presents a significant threat to food security for coastal communities. These examples underscore the urgent need for climate-adaptive management strategies to ensure the sustainability of fisheries.

In other regions, such as Lake Victoria and Southeastern Australia, ecosystem degradation and shifting species distributions due to warming waters highlight the complexity of managing fisheries in a changing environment. The introduction of mitigation strategies like cage culture and the use of genomic analyses for understanding species adaptability are crucial for proactive management. Overall, the changing temperature dynamics across various ecosystems necessitate adaptive approaches to sustain fisheries and protect the livelihoods dependent on these resources. The importance of spatial modelling and Bayesian approaches in fisheries management can explain discarding practices and their ecological effects. This approach, using Bayesian hierarchical models, provides insight into the spatial distribution of waste, helping to identify areas that require regulatory focus. Hydrodynamic modelling, based on real river geometry, and Habitat Suitability Index (HSI) are also essential to optimize fish spawning habitat and manage fishing pressure to ensure appropriate ecological conditions for population sustainability and fish health. The use of remote sensing models and Lagrangian propagation supports the conservation of marine resources for high-precision monitoring, especially in fishing activities. In addition, self-organizing maps (SOMs) and clustering techniques support the implementation of sustainable fisheries by providing innovative methods to visualize the location of fishing grounds as well as the provision of complex fisheries data. These methods collectively contribute to more informed decision-making in fisheries management and promote the long-term sustainability of marine ecosystems.

As a conclusion, the protection of fish spawning aggregations is critical due to the heightened vulnerability of species during their reproductive periods. Successful management of these sites hinges on the integration of local ecological knowledge and the implementation of marine protected areas (MPAs), which are essential for conserving fish populations and enhancing ecosystem resilience. The influence of temperature on species distribution and co-occurrence is a significant factor in understanding climate change's broader impacts on marine ecosystems. Temperature variations are altering the spatial distribution and interaction of species, affecting their ecological roles and availability to fisheries. This necessitates climate-adaptive management strategies to sustain fisheries and protect livelihoods, particularly in regions facing severe environmental changes. The application of spatial modelling and Bayesian approaches in fisheries management offers valuable insights into discarding practices and their ecological impacts, while hydrodynamic modelling and Habitat Suitability Indexes (HSIs) are vital for optimizing fish-spawning habitats and managing fishing pressure. Ecological assessments highlight the importance of habitat diversity in sustaining fish populations, with remote sensing and Lagrangian dispersion models providing precision in monitoring fishing activities. Self-organizing maps (SOMs) and clustering techniques offer innovative methods for visualizing complex fisheries data, identifying catch hotspots, and supporting sustainable fishing practices. Collectively, these tools and strategies contribute to more informed decision-making in fisheries management, ensuring the long-term sustainability of marine ecosystems.

Acknowledgements
This work was supported by funding by the Ministry of Higher Education Malaysia under the Hadiah Latihan Persekutuan scholarship.

Conflicts of Interest
The authors declare that they have no conflicts of interest to report regarding the present study.

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DOI: 10.35631/IJEMP.728002

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