The Eurasia Proceedings of Health, Environment and Life Sciences (EPHELS)
ISSN: 2791-8033

The Eurasia Proceedings of Health, Environment and Life Sciences (EPHELS), 2026

Volume 21, Pages 33-40

ICVALS 2026: International Conference on Veterinary, Agriculture and Life Sciences

Impact of Natural Disaster and Essential Spawning Habitat (ESH) Characteristics on the Conservation of the Vulnerable Endemic Bilih Fish (*Mystacoleucus padangensis*) in Lake Singkarak, Indonesia

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Abstract: The Bilih fish *(Mystacoleucus padangensis)* is a high value endemic species critical to regional aquaculture biosystems. Currently listed as Vulnerable (VU) on the IUCN Red List, its wild stocks are facing an acute ecological and economic crisis, evidenced by a dramatic 99% collapse in catch volume (from 1 ton/day in 2002 to only 10 kg/day in 2025). This study aimed to characterize the Essential Spawning Habitat (ESH) and governing reproductive strategies, and to develop conservation management principles. Environmental metrics and habitat characteristics (substrate, depth) were measured. Results confirmed that the ESH functions as a critical biosystem component, defined by extremely shallow waters (4–16 cm) and sandy and rocky substrates. Precise environmental cues, specifically consistently low nocturnal temperatures (22–24°C), act as triggering inputs for migration and spawning. This existing stock crisis was severely exacerbated by a catastrophic flood and landslide event that occurred on November 27, 2025, in the spawning locality of West Sumatra. The disaster resulted in the critical degradation of the ESH, primarily through infilling the original substrate with unsuitable mud and fine sand. This damage effectively eliminated the essential rocky spawning media required for behavioral triggering, consequently disrupting the remaining reproductive cycle and accelerating the failure of current resource management efforts. Given the evident high sensitivity of the reproductive process to specific biosystem inputs and the physical destruction of the ESH by the natural disaster, this study urgently recommends strict conservation zoning and ecology based management. Crucially, these must be immediately followed by habitat restoration efforts to reinstate the necessary rocky substrate. Such measures are vital inputs for the regional biosystem, not only to prevent the immediate loss of this Vulnerable endemic germplasm but also to secure the biological foundations required for future resource recovery and sustainable ex-situ aquaculture development.

Keywords: Bilih fish (*Mystacoleucus padangensis*), Essential spawning habitat, Stock collapse, Flood and landslide, Habitat restoration

Introduction

Southeast Asian river systems are increasingly subject to intense natural disturbances, notably flash floods and landslides. These events are driven by monsoonal rainfall, steep topography, and, increasingly, anthropogenic land-use changes. Flash floods rapidly mobilize large volumes of sediment and debris, while landslides contribute pulses of fine and coarse material to river channels. Both processes can dramatically alter river morphology, substrate composition, and habitat complexity, with cascading effects on aquatic communities and spawning habitat quality (Kuksina et al., 2020; Zhang et al., 2025). Flood events are a primary factor regulating aquatic ecosystem dynamics and influencing fish community structure and essential habitat functions (Taylor et al., 2017). Indonesia is a designated megabiodiversity nation, geographically divided into the global biodiversity hotspots of Wallacea and Sundaland, both exhibiting remarkably high levels of endemism (*Conservation*

International, 2024). The phenomenon observed in Lake Singkarak can be interpreted through the concept of hydrological disturbance affecting spawning habitats, similar to processes described in studies of the Kariega Estuary, although the ecological outcomes differ. While flood events in the Kariega Estuary have been reported to improve ecosystem conditions and restore habitat functionality (Nodo et al., 2018), the catastrophic flood and landslide event that occurred on November 27, 2025, in Lake Singkarak led to the critical degradation of the ESH. Among the crucial endemic species is the Bilih fish *Mystacoleucus padangensis*, found exclusively in Lake Singkarak, West Sumatra. The Bilih fish population has recently experienced a drastic decline, resulting in its conservation status being officially listed as "Vulnerable" by the IUCN since 2020 (IUCN, 2020). Furthermore, analyses such as the Productivity and Susceptibility Analysis (PSA) have assigned the species a high vulnerability index to exploitation (Syandri et al., 2023; Triharyuni et al., 2022). *Mystacoleucus padangensis*, an endemic riverine cyprinid, plays a pivotal role in Southeast Asian freshwater ecosystems. Its essential spawning habitats (ESH) are characterized by clean, well-oxygenated, heterogeneous gravel beds that support successful egg incubation and larval emergence. These habitats underpin not only the persistence of *M. padangensis* populations but also broader riverine biodiversity and ecosystem function. The species' reproductive success is tightly linked to the physical and chemical integrity of these gravel substrates, making them highly sensitive to environmental disturbances, particularly sedimentation events that alter substrate permeability and oxygen dynamics (Kawanishi et al., 2010; Kumar et al., 2025)

The Bilih fish plays a critical ecological, social, and economic role for the surrounding communities. Economically, the species is the primary source of livelihood for a majority of local fishermen. Nutritionally, its flesh is highly valued, containing significantly higher levels of protein, calcium, iron,Vitamin A, Vitamin E, and zinc compared to many other animal and plant-based food sources (Putri & Syamsir, 2020; Yuniritha et al., 2015). This exceptional nutritional value and high market demand have driven the commercial price of Bilih fish to surge dramatically (Ikhsan & Fitrisia, 2024). However, this escalating demand has resulted in severe overexploitation, primarily targeting the species in river estuaries which serve as their spawning habitats, consequently leading to a decline in wild stock (Triharyuni et al., 2022). This situation not only threatens the species long term survival but also creates economic instability for the fishing communities reliant on Lake Singkarak (Ikhsan & Fitrisia, 2024). Fish require not only suitable spawning habitats but also effective connectivity to larval and nursery habitats. When larvae are unable to reach appropriate rearing environments due to hydrodynamic barriers or excessive swimming energy costs, larval survival rates decline, juvenile recruitment decreases, and long-term population size may be negatively affected. Therefore, reproductive success is determined not only by the quality of spawning sites but also by the ability of larvae to disperse toward habitats that support early growth and development (Holzapfel et al., 2026).

Method

Study Area

This study was conducted at the natural spawning grounds of the Bilih fish (*Mystacoleucus padangensis*) located in the inflow areas of Lake Singkarak, West Sumatra, Indonesia. The study area represents a historically recognized reproductive habitat for this endemic cyprinid species. Field observations were carried out in the spawning locality both prior to and following a major flood and landslide event that occurred on 27 November 2025, which substantially altered the physical structure of the habitat.

Research Design

This research employed a descriptive–analytical field study design, focusing on in situ observation of environmental conditions and habitat characteristics associated with spawning activity. The study did not involve experimental manipulation, capture, or invasive handling of animals. All observations were limited to habitat features and abiotic parameters relevant to reproductive ecology. It is important to note that these observations were conducted before disaster and one week post disaster under extreme environmental conditions. The study area was designated as a "Red Zone" due to ongoing heavy rainfall and the high risk of secondary landslides. Consequently, for safety reasons and following local evacuation protocols, visual monitoring was limited to the early evening and could not be extended into the night. However, the absence of fish during the initial migratory window (up to 18:00 WIB) in the impacted zone contrasted with their presence in healthy zones provides a robust indicator of habitat rejection. These logistical constraints underscore the severity of the "Natural Disaster" mentioned in the title, highlighting that the threat to this vulnerable endemic species is not only the initial event but the ongoing unstable conditions of the post disaster environment.

Environmental and Habitat Data Collection

Environmental Parameters

Water temperature (°C) was measured using portable water quality meters. Measurements was conducted during both daytime and nocturnal periods to capture environmental fluctuations potentially acting as spawning cues. Special attention was given to nocturnal temperature patterns, which are known to influence migratory and reproductive behavior in rheophilic cyprinid fishes.

Habitat Characteristics

Habitat characteristics were assessed through direct field observation and manual measurement. Water depth (cm) was measured using a calibrated ruler along multiple transects across the spawning area. Substrate composition was visually classified into sand, gravel, rock, and fine sediment (mud), with emphasis on identifying the presence or absence of rocky substrates functioning as spawning media.

Data Analysis

Collected environmental and habitat data were analyzed descriptively to determine the defining characteristics of the Essential Spawning Habitat (ESH). Observed parameter ranges were interpreted in relation to established ecological concepts of habitat suitability for lithophilic and rheophilic spawners. Habitat degradation following the flood event was assessed qualitatively by comparing pre and post disturbance substrate conditions, particularly focusing on sediment infilling and loss of rocky spawning substrates.

Results and Discussion

Figure 1. *Substrate conditions in the spawning habitat of the endemic Bilih fish (Mystacoleucus padangensis) in Lake Singkarak.* ***Figure A and B****, Natural environmental conditions of the spawning grounds (breeding sites) of prior to the disaster, characterized by high water transparency and a stable shoreline morphology.* ***Figure C****, Characteristics of the pristine spawning substrate consisting of a heterogeneous mixture of gravel and coarse sand, providing essential interstitial spaces for egg attachment and aeration.* ***Figure D****, Immediate post-disaster impact of the flood and landslide on the spawning site.* ***Figure E****, Post-disaster recovery phase showing improved water clarity, yet revealing a significant accumulation of fine-grained alluvial deposits (silt and clay) smothering the benthic layer.* ***Figure F****, Close-up detail of the altered substrate texture.*

Mystacoleucus padangensis is an endemic species of Lake Singkarak characterized by highly specific spawning behavior, involving migration to river estuaries or lacustrine shorelines with distinct water currents and rocky substrates. However, these vital breeding sites underwent severe physical disruption following the catastrophic flood and landslide event on November 27, 2025, which transported massive volumes of terrestrial soil and mud from the upstream catchments to the lake's littoral zones. Floods are among the most significant natural disturbances shaping the physical and ecological characteristics of lake and river ecosystems. Their impacts on

spawning substrate and essential spawning habitat (ESH) are profound, influencing the reproductive success and long-term viability of endemic freshwater fish species.

The substrate conditions within the Essential Spawning Habitat (ESH) of the endemic *Bilih fish (Mystacoleucus padangensis)* in Lake Singkarak exhibited a drastic transformation following the flood and landslide event on November 27, 2025. Visual observations of the natural environmental conditions prior to the disaster characterized the spawning grounds by high water transparency and stable shoreline morphology (Figures A and B). The pristine spawning substrate consisted of a heterogeneous mixture of gravel and coarse sand (Figure C), which provided essential interstitial spaces for egg attachment and critical aeration during the incubation period.

In the immediate aftermath of the disaster, the flood and landslide exerted a catastrophic impact on the spawning site (Figure D). Although the post-disaster recovery phase showed signs of improved water clarity, it revealed a significant accumulation of fine-grained alluvial deposits (silt and clay) smothering the entire benthic layer (Figure E). Close-up details of the altered substrate texture (Figure F) confirm the loss of essential voids due to sediment infilling. The comparative environmental parameters before and after the disaster are summarized in the following table:

Table 1. Comparative before and after disaster

No	Parameter	Pre Disaster	Post Disaster	Significance
1.	Significance Nocturnal Temperature	22–24°C	23–24°C (No significant difference)	Thermal trigger was present but ineffective due to substrate failure
2.	Water Depth	4–16 cm	4-9 cm	Habitat availability in terms of volume was maintained
3.	Substrate Texture	Heterogeneous Gravel/Sand	Dense Yellowish Silt	The primary driver of reproductive failure (Clogging).
4.	Particle Size (D50)	0.5 cm – 3.5 cm	0.21 mm (fine silt)	Mechanical "cementing" of voids
5.	Intersitial space	High (for aeration and ptotection)	Zero (completely infilled)	Embryonic asphyxiation
6.	Permeability	Permeability High (Oxygen diffusion)	Impermeable	Embryo mortality
7.	Visual Status	High transparency (Fig. A)	Ochre-colored turbidity (Fig. D)	Ethological barrier for spawners

The documented substrate transformation reveals a catastrophic failure of the Essential Spawning Habitat (ESH) driven by complex sedimentation mechanisms. Prior to the disaster, the spawning site maintained a heterogeneous matrix of pebbles ranging from 3 cm to 0.5 cm. According to (Franssen et al., 2012) the presence of coarse sand and fine gravel, with a coarse material proportion exceeding 18%, should theoretically function as a natural filter to mitigate the infiltration of fine sediments into deeper layers. However, the flash flood triggered a surge in fine-to-coarse particle ratios that bypassed this natural filtration capacity. The dominance of sediments with a median diameter D50 of approximately 0.21 mm, which (Hsu et al., 2018) identify as highly effective in forming impermeable layers, initiated a massive clogging process. This was subsequently exacerbated by the formation of cohesive clay deposits on the surface layer (as seen in Figure F). This clay layer effectively "cemented" the gravel matrix, creating an absolute impermeable seal that severed dissolved oxygen diffusion into the substrate voids. Consequently, despite stable nocturnal temperatures of 23–24°C, the physical degradation of the ESH led to total embryonic mortality via asphyxiation and established a significant ethological barrier for adult spawners.

Southeast Asian river systems are increasingly subject to intense natural disturbances, notably flash floods and landslides. These events are driven by monsoonal rainfall, steep topography, and, increasingly, anthropogenic land-use changes. Flash floods rapidly mobilize large volumes of sediment and debris, while landslides contribute pulses of fine and coarse material to river channels. Both processes can dramatically alter river morphology, substrate composition, and habitat complexity, with cascading effects on aquatic communities and spawning habitat quality (Kuksina et al., 2020; Zhang et al., 2025) As an endemic riverine cyprinid, *Mystacoleucus padangensis* plays a pivotal role in these freshwater ecosystems. Its ESH is characterized by clean, well-oxygenated, heterogeneous gravel beds that support successful egg incubation and larval emergence. The reproductive success of this species is tightly linked to the physical and chemical integrity of these gravel substrates, making them highly sensitive to environmental disturbances particularly sedimentation events that alter substrate permeability and oxygen dynamics (Kawanishi et al., 2010; Kumar et al., 2025).

The phenomenon observed in Lake Singkarak can be interpreted through the concept of hydrological disturbance affecting spawning habitats, similar to processes described in the Kariega Estuary, although the ecological outcomes differ. While flood events in the Kariega Estuary have been reported to improve ecosystem conditions and restore habitat functionality (Nodo et al., 2018) floods in this context acted as a primary destructive agent. While flooding is a major factor regulating aquatic ecosystem dynamics and influencing fish community structures (Taylor et al., 2017), landslides often deposit fine sediments that severely degrade spawning habitat suitability. For instance, Schizothorax species impacted by the 2018 Baige Landslide Dam showed a decreased ability to survive due to changes in riverbed substrates and flow conditions (Xie et al., 2024) Furthermore, increased fine sediment due to climate change and land use changes can clog gravel beds, impeding spawning and reducing recruitment rates for species such as brown trout (Scheurer et al., 2009). This is supported by the fact that substrate particle size is a strong predictor of "survival to emergence," with lithophilic cyprinids exhibiting sensitivities similar to salmonids (Young et al., 1990).

Anthropogenic factors, such as water level fluctuations from hydropower operations, can further compress viable spawning habitats into smaller areas, particularly affecting species with specialized spawning strategies (Wang et al., 2026; Xiang et al., 2025) Low-flow periods exacerbated by over-abstraction can also reduce habitat availability (Garbe et al., 2016). Ultimately, behavioral adaptations, such as retreat movements or diel activity shifts, highlight the critical importance of habitat quality in facilitating successful spawning migration (Bentley et al., 2014; Jubb et al., 2023). Without a functional substrate, the entire reproductive cycle of the Bilih fish is effectively terminated.

Ultimately, this sequence of ecological degradation poses a profound threat to population sustainability, given that the recruitment of *Mystacoleucus padangensis* in Lake Singkarak is heavily dependent on the success of these specific spawning grounds. If the breeding sites remain smothered by fine sediments over an extended period, adult fish may lose the environmental triggers required for spawning or be forced to spawn in suboptimal locations, resulting in drastically reduced survival rates. This is further emphasized by Figure E, which reveals that despite the gradual recovery of water clarity, the "ecological scar" on the lake bed persists as a thick mud layer. The natural restoration of these sites will require an extensive period or high-velocity discharge events to flush the fine sediments and re-expose the original gravel and coarse sand matrix. Understanding these processes is critical for effective conservation and management, especially in the context of increasing anthropogenic pressures and climate variability. This report synthesizes current knowledge on how floods alter spawning substrates and ESH, the consequences for fish reproduction, and the implications for conservation strategies in both regulated and unregulated systems

Conclusion

The catastrophic flood and landslide event of November 27, 2025, caused severe1 physical degradation of the spawning habitat by infilling the original rocky substrate with fine sediment and mud. This alteration effectively eliminated the essential spawning media required for reproductive triggering, leading to further disruption of the already declining reproductive cycle. The destruction of the Essential Spawning Habitat has accelerated the failure of existing resource management efforts and poses an immediate threat to the persistence of remaining wild populations.

Overall, the findings confirm that habitat degradation, rather than biological limitation alone, represents the primary driver of the current stock collapse of this Vulnerable endemic species. This study demonstrates that the reproductive success of *Mystacoleucus padangensis* is highly dependent on a narrowly defined Essential Spawning Habitat characterized by extremely shallow water depths (4–16 cm) and sandy–rocky substrates. Consistently low nocturnal water temperatures (22–24°C) function as critical environmental triggers for upstream migration and spawning behavior, indicating a high sensitivity of the species reproductive process to specific abiotic cues.

Recommendations

Based on the high sensitivity of the bilih fish reproductive process to specific habitat and environmental inputs, this study recommends the immediate implementation of strict conservation zoning in all identified spawning areas. Human activities that alter substrate composition, hydrology, or sediment load should be strictly regulated within these zones.

Ecology-based management strategies must be prioritized, emphasizing habitat restoration as a core conservation action. Restoration efforts should focus on reinstating the original rocky substrate composition necessary for spawning behavior, particularly in areas impacted by sediment infilling following natural disasters.

In addition, long-term monitoring of environmental parameters and habitat integrity is strongly recommended to ensure the continued functionality of Essential Spawning Habitats. These measures are critical not only to prevent the imminent loss of this Vulnerable endemic germplasm but also to establish the ecological foundations required for future stock recovery and the development of sustainable ex situ aquaculture programs.

Scientific Ethics Declaration

* The authors declare that the scientific, ethical, and legal responsibility of this article published in the EPHELS Journal belongs to the authors.

* This study did not require ethics committee approval as it involved no experimental manipulation or invasive procedures on animals

Conflict of Interest

* The authors declare that they have no conflicts of interest.

Funding

* The authors wish to express profound gratitude for the support received during the implementation of this research. We extend our sincere acknowledgment to Indonesia Endowment Fund for Education (LPDP) Ministry of Finance, Republic of Indonesia for providing comprehensive funding through.

Acknowledgements or Notes

* This article was presented as an oral presentation at the International Conference on Veterinary, Agriculture and Life Sciences (www.icvals.net) held in Konya/Türkiye on April 02-05, 2026.

* The authors wish to express profound gratitude for the support received during the implementation of this research. We extend our sincere acknowledgment to Indonesia Endowment Fund for Education (LPDP) Ministry of Finance, Republic of Indonesia for providing comprehensive funding through. Furthermore, we are deeply appreciative of the invaluable technical guidance and academic direction received from the Laboratory of Functional and Developmental Animal Biology, Faculty of Biology, Universitas Gadjah Mada (UGM), whose provision of dedicated laboratory facilities was instrumental in the successful execution and analysis of this study.

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To cite this article:

Adelfiani, A. & Retnoaji, B. (2026). Impact of natural disaster and essential spawning habitat (ESH) characteristics on the conservation of the vulnerable endemic Bilih fish (*Mystacoleucus padangensis*) in lake Singkarak, Indonesia. *The Eurasia Proceedings of Health, Environment and Life Sciences (EPHELS), 21,* 33-40.