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LEGAL AND CULTURAL DIMENSIONS OF TERUBUK FISH (TENUALOSA ILISHA) CONSERVATION IN INDONESIA: FROM FISHERIES POLICY TO DIGITAL HERITAGE OF AQUATIC BIODIVERSITY

Sriono[1*], Ika Chastanti[1], Ali Akbar Ritonga[1]

[1]Universitas Labuhanbatu, Indonesia. sriono@ulb.ac.id, https://orcid.org/0000-0002-4655-7715, chastanti.ika@gmail.com, https://orcid.org/0000-0002-6877-6652, aliakbarritonga@gmail.com, https://orcid.org/0000-0002-3856-9353

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Corresponding Author: sriono (sriono@ulb.ac.id)

ABSTRACT

The Terubuk fish (Tenualosa ilisha) holds ecological, economic, and cultural significance in Indonesia, particularly in Labuhanbatu, yet faces severe threats from overfishing, habitat degradation, pollution, and weak law enforcement. This study employs a qualitative case study approach to examine the legal, cultural, and digital dimensions of Terubuk conservation. Data were collected through legislative review, semi-structured interviews with government agencies, law enforcement (Polairud, TNI AL), community monitoring groups, and fishers, as well as field observations and secondary scientific data. Findings reveal that while Indonesia has a strong legal foundation for fisheries and environmental protection, implementation remains weak due to fragmented institutional coordination, insufficient sanctions against IUU fishing, and limited community participation. Ecological assessments confirm declining population resilience, exacerbated by genetic isolation and pollution from palm oil effluents. Culturally, Terubuk is central to local identity and traditions, yet these dimensions are marginalized in policy frameworks. The proposed "3P Conservation Model" Policy, Protection, and People integrates adaptive legal instruments, habitat restoration, digital monitoring technologies (eDNA, blockchain, drones), and community empowerment through incentives and cultural heritage recognition. This model underscores that effective conservation must transcend rigid regulation, embedding local knowledge and cultural symbolism while leveraging digital innovation for transparency and accountability. By positioning T. ilisha as both a biological resource and living cultural heritage, this study contributes a replicable framework for migratory fish conservation in Southeast Asia, aligning biodiversity protection with cultural preservation and digital sustainability.

KEYWORDS: Terubuk Fish, Conservation Policy, Cultural Heritage, Digital Innovation, Indonesia.

1. INTRODUCTION

The Terubuk Fish (Tenualosa ilisha), known locally as Terubuk, is a migratory fish species of high ecological, economic, and cultural importance across Asia, including Indonesia (Machrizal et al., 2024). Historically, Terubuk has been intertwined with the fisheries and cultural identity of coastal communities in Sumatra, particularly in Bengkalis and Labuhanbatu, since the 19th century (Syahrian & Rahmat, 2023). Beyond its role as a food source, Terubuk has been embedded in local traditions, culinary practices, and communal identity, making its conservation not only an ecological concern but also a cultural heritage issue.

At present, the species faces escalating threats. Overexploitation, habitat degradation, and weak law enforcement have significantly reduced its population (Segura-García et al., 2024; Siregar et al., 2020). Ecologically, T. ilisha contributes to the stability of estuarine and coastal ecosystems. Genetic studies confirm that the Terubuk population in Labuhanbatu possesses unique genetic markers distinct from other Asian populations, requiring site-specific conservation strategies (Machrizal et al., 2024).

Nevertheless, the spread of Illegal, Unreported, and Unregulated (IUU) fishing, coupled with non-selective gear, has exacerbated population decline (Fatmawati et al., 2023; Liu et al., 2025). Furthermore, wetland conversion and aquatic pollution, particularly industrial wastewater discharges, continue to erode Terubuk habitats (Naswar et al., 2023; Longin et al., 2021).

In terms of regulation, Indonesia has established a legal basis for fishery management and environmental protection through Law No. 31 of 2004 concerning Fisheries and Law No. 32 of 2009 concerning Environmental Protection and Management (Syahrian & Rahmat, 2023). However, practical implementation at the local level remains weak due to limited resources, lack of coordination, and low public awareness (Batubara et al., 2021). In Labuhanbatu, despite initiatives by the local Marine and Fisheries Office, efforts remain constrained by the absence of specific regional bylaws (Perda) (Siregar et al., 2020).

The Minister of Marine Affairs and Fisheries Decree No. 43/KEPMEN-KP/2016 provides a formal framework for Terubuk protection in Labuhanbatu, but its scope remains limited and largely regulatory in nature. The limitations of this protection are detailed in Figure 1 and Table 1 below

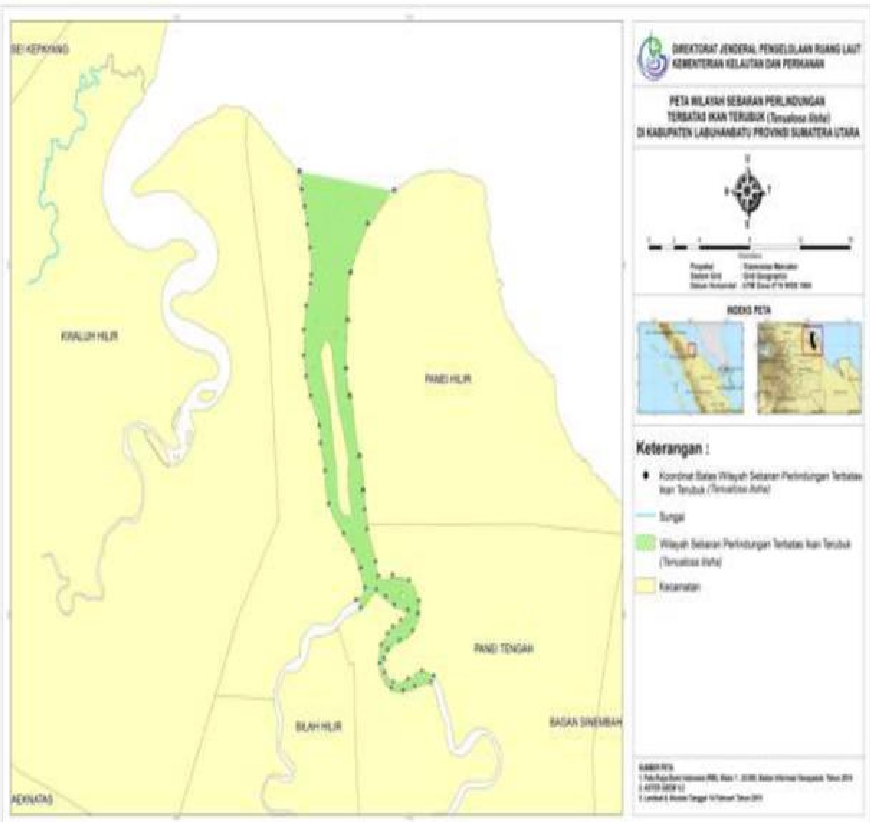

Figure 1: Map of the Limited Protection Area for Hilsa Shad (Tenualosa ilisha).

Table 1: Coordinate Points for the Limited Protection Zone of Terubuk Fish (Tenualosa ilisha).

No	Titik Koordinat		No	Titik Koordinat	
	Bujur Timur	Lintang Utara		Bujur Timur	Lintang Utara
1	100°5' 16.800"	2°42' 39.600"	31	100°8' 41.670"	2°28' 34.913"
2	100°9' 19.616"	2°42' 7.294"	32	100°8' 48.062"	2°29' 8.520"
3	100°8' 12.722"	2°41' 10.762"	33	100°9' 2.593"	2°29' 25.984"
4	100°7' 27.091"	2°39' 47.016"	34	100°9' 17.262"	2°29' 37.854"
5	100°7' 19.989"	2°38' 23.917"	35	100°9' 36.039"	2°29' 49.687"
6	100°7' 16.048"	2°37' 1.365"	36	100°9' 55.569"	2°30' 5.362"
7	100°7' 25.906"	2°36' 16.293"	37	100°9' 21.905"	2°30' 16.413"
8	100°7' 51.428"	2°34' 32.466"	38	100°8' 57.034"	2°30' 28.756"
9	100°8' 0.970"	2°33' 32.118"	39	100°8' 35.648"	2°30' 40.826"
10	100°8' 5.190"	2°32' 58.161"	40	100°7' 53.811"	2°30' 11.530"
11	100°8' 11.037"	2°32' 24.947"	41	100°7' 42.247"	2°30' 25.150"
12	100°8' 32.880"	2°31' 29.481"	42	100°8' 4.091"	2°30' 45.195"
13	100°8' 39.969"	2°31' 4.690"	43	100°7' 53.289"	2°31' 15.878"
14	100°9' 17.231"	2°31' 7.003"	44	100°7' 35.129"	2°31' 50.485"
15	100°10' 0.147"	2°30' 57.237"	45	100°7' 10.116"	2°32' 18.239"
16	100°10' 23.275"	2°30' 21.774"	46	100°6' 31.740"	2°33' 9.807"
17	100°10' 21.733"	2°29' 58.388"	47	100°6' 21.803"	2°34' 4.287"
18	100°10' 7.599"	2°29' 32.176"	48	100°6' 10.578"	2°34' 54.091"
19	100°9' 34.005"	2°29' 16.571"	49	100°6' 7.179"	2°35' 25.952"
20	100°9' 3.596"	2°28' 59.444"	50	100°5' 45.661"	2°36' 12.800"
21	100°8' 51.747"	2°28' 44.095"	51	100°5' 31.887"	2°36' 48.778"
22	100°8' 57.888"	2°28' 20.165"	52	100°5' 27.626"	2°37' 22.947"
23	100°9' 16.760"	2°28' 1.950"	53	100°5' 27.541"	2°38' 8.476"
24	100°9' 55.526"	2°28' 7.091"	54	100°5' 33.537"	2°38' 49.593"
25	100°10' 31.718"	2°28' 22.724"	55	100°5' 45.493"	2°39' 25.932"
26	100°11' 2.200"	2°28' 14.076"	56	100°5' 47.696"	2°39' 41.257"
27	100°10' 57.703"	2°28' 3.797"	57	100°5' 44.099"	2°40' 26.743"
28	100°10' 12.282"	2°27' 55.767"	58	100°5' 38.188"	2°41' 7.346"
29	100°9' 41.787"	2°27' 47.886"	59	100°5' 29.665"	2°41' 38.959"
30	100°9' 13.536"	2°27' 52.768"	60	100°5' 21.998"	2°42' 8.251"

From a broader perspective, conservation of Terubuk must also be seen through its cultural significance. The fish symbolizes continuity of local identity and traditions, yet such cultural dimensions are often absent in policy discussions. Moreover, with the advancement of digital technologies, conservation can be strengthened by creating digital heritage archives, blockchain-based monitoring systems, and knowledge-sharing platforms that document both ecological data and cultural narratives surrounding Terubuk. In this sense, conservation is not only about ecological sustainability but also about safeguarding a living heritage through an integrated legal, cultural, and digital framework.

Conservation challenges for the Terubuk shad are also deeply connected to the socio-economic and cultural dimensions of coastal communities. In Labuhanbatu, many fishers still rely heavily on Terubuk catches as their main source of income (Fatmawati et al., 2023). The absence of alternative livelihoods and insufficient economic incentives often compels them to overlook sustainable practices (Longin et al., 2021).

At the same time, Terubuk holds symbolic value as part of local culinary traditions and cultural identity, meaning that its depletion threatens not only ecological balance but also the preservation of intangible heritage. Lessons from Bangladesh show that incentive-based programs such as seasonal fishing bans combined with financial compensation can restore Terubuk populations while improving fishers' welfare (Bergseth et al., 2018). This suggests that combining ecological and cultural incentives may provide a more sustainable pathway for Indonesia.

Technological innovation also opens new opportunities. In China, DNA barcoding has been used successfully to track and deter illegal trade of Terubuk (Liu et al., 2025). Likewise, digital water-quality monitoring systems have proven effective in enhancing surveillance and enforcement (Urbano et al., 2023). Beyond ecology, digital platforms can be employed to archive and disseminate the cultural narratives of Terubuk, transforming it into a form of digital heritage accessible to both local communities and global audiences.

Yet, in Indonesia, the adoption of such tools is still constrained by limited infrastructure, financial resources, and human capacity (Plekhanov et al., 2023).

Building on these perspectives, this article aims to examine the conservation of Terubuk fish through three integrated dimensions: (1) the legal and policy framework, (2) cultural heritage and community participation, and (3) the role of digital innovation in biodiversity protection. By employing an interdisciplinary approach that combines law, ecology, socio-economics, and digital heritage studies, this research seeks to offer holistic recommendations for the conservation of T. ilisha in Indonesia.

The findings are expected to inform both policymakers and local stakeholders while also providing a replicable model for other migratory fish species conservation in Southeast Asia. In this way, protecting Terubuk is not only about saving a threatened species but also about sustaining cultural identity, strengthening digital heritage, and securing the well-being of coastal communities for future generations.

2. METHOD

This study employed a qualitative case study design to investigate the legal, cultural, and ecological dimensions of Terubuk fish (Tenualosa ilisha) conservation in Labuhanbatu Regency, Indonesia. An interdisciplinary approach was applied, integrating perspectives from environmental law, fisheries policy, socio-cultural studies, and digital heritage to generate a holistic understanding of conservation challenges and opportunities. The research was centered on the Barumun River basin and its estuarine area, which serve as critical spawning habitats for T. ilisha and represent key cultural landscapes for local communities.

Data collection was conducted using three primary techniques. First, document analysis focused on national and regional legislative frameworks related to fisheries conservation, environmental protection, and cultural heritage, including Law No. 31/2004 on Fisheries, Law No. 32/2009 on Environmental Protection and Management, and Ministerial Decree No. 43/KEPMEN-KP/2016. Second, semi-structured interviews were carried out with 30 key informants, comprising government officials, fisheries and environmental law enforcement (Polairud, TNI AL), local fishers, Community Monitoring Groups (Pokmaswas), and cultural leaders, to capture both regulatory insights and community perceptions.

The selection of interview participants was conducted through purposive sampling to ensure the inclusion of diverse stakeholder perspectives. Criteria included institutional role, experience in fisheries or environmental management, and proximity to the Barumun estuarine ecosystem. Among the 30 informants, 17 were local fishers (aged 25–65) representing different villages along the Barumun River, 3 were officials from fisheries and environmental agencies, 2 were law enforcement officers, 5 were Pokmaswas members, and 3 were community and cultural leaders. This demographic spread allowed for triangulation between regulatory authorities, enforcement personnel, and resource users at the community level.

Third, field observations documented ecological conditions, fishing activities, and cultural practices linked to Terubuk. In addition, secondary data from scientific reports, policy documents, fisheries statistics, and digital monitoring initiatives were reviewed.

Data analysis was qualitative and conducted in multiple stages. Policy analysis was used to assess the alignment of fisheries and environmental regulations with biodiversity and heritage protection principles. Thematic analysis, supported by NVivo 12 software, was applied to interview data to identify recurring themes across ecological, legal, socio-economic, and cultural dimensions. Comparative analysis was conducted to benchmark Indonesian conservation practices against best practices in countries such as Bangladesh and China, particularly regarding incentive-based conservation and digital monitoring systems.

Validity and reliability were strengthened through data triangulation (documents, interviews, field observations), member checking with informants, and expert reviews. Ethical protocols were observed by securing informed consent, ensuring confidentiality, and verifying data accuracy prior to publication. This research acknowledges its limitations in geographic scope and secondary data availability. However, by combining law, culture, and digital heritage perspectives, it provides a robust basis for comprehensive policy recommendations and a replicable model of aquatic biodiversity governance in Southeast Asia.

3. RESULT AND DISCUSSION

3.1. Legal, Institutional, and Cultural Dimensions

National regulations concerning fish conservation in Indonesia possess a strong legal foundation, ranging from the Fisheries Law to policies on protected species conservation. However, the study by Syahrian & Rahmat (2023) affirms the existence of a paradox in Indonesian fisheries governance: the misalignment between formal institutions (state law) and informal norms (local practices). A similar condition is observed in the case of the Terubuk shad, where formal regulations do not fully address the needs and practices of coastal communities.

Interviews with the Marine and Fisheries Office in Labuhanbatu revealed that institutional coordination remains weak: key agencies such as the Water Police (Polairud), the Indonesian Navy (TNI AL), and Community Monitoring Groups (Kelompok masyarakat pengawas - Pokmaswas) are not yet optimally involved. This aligns with the findings of Fidelman & Ekstrom (2020), who state that a fragmented institutional architecture creates gaps in policy implementation. In fisheries governance, a tension exists between efficiency, equity, and fishers' (Jentoft & Knol, 2014). The case of the Terubuk shad in Labuhanbatu shows that conservation policies are often perceived merely as restrictions on fishers' activities without providing equitable alternatives. This is consistent with Bennett et al., (2021) study on the risks of "blue growth" overlooking blue justice for local communities. Furthermore, fishers identified the primary cause of population decline not solely as fishing activity, but also pollution from palm oil mill effluent in the Barumun and Bilah Rivers, which serve as critical spawning habitats. This phenomenon underscores a disconnect between law and ecology (Cinner et al., 2012), as legal policies often fail to accommodate real-world ecological factors.

Within marine conservation literature, policy effectiveness is highly influenced by social synergy and co-management mechanisms. Sutinen & Kuperan, (1999) demonstrate that conservation policies often result in trade-offs between beneficiaries and those who are disadvantaged. In the case of the Terubuk shad, coastal communities feel more sacrificed than involved. Oberhauser, (2019) emphasize the importance of local context for the success of community-based conservation. However, in Labuhanbatu, the Community Monitoring Groups (Pokmaswas), which should be government partners, are still not fully empowered. Conversely Bergseth et al., (2018) prove that community-based surveillance can be an effective instrument in reducing poaching.

Illegal, unreported, and unregulated (IUU) fishing practices remain a serious threat in Southeast Asia. Thompson et al., (2021) identify this region as one of the largest IUU fishing hotspots. In Labuhanbatu, weak cross-institutional coordination and minimal involvement of law enforcement agencies (Polairud, TNI AL) exacerbate policy ineffectiveness. This condition aligns with Ostrom's theory on the necessity of polycentric governance principles for more robust oversight (Williams & Brown, 2014). Beyond local issues, the exploitation of the Terubuk shad is also driven by market demand. Hedegaard Sørensen & Paulsson, (2020) reveal that trade factors are often overlooked in fisheries policy design, despite being a primary driver of overexploitation. This is highly relevant for the Terubuk shad, a known high-value commodity, which encourages unregulated hunting.

The migratory nature of the Terubuk shad demands adaptive governance. Allendorf, (2017) emphasize the importance of adaptive governance for managing dynamic resources. However, Indonesia's legal framework tends to be rigid, making it difficult to respond to population changes and external threats, including industrial pollution. Furthermore, the integration of scientific data, such as species distribution modelling (Espinel-Velasco et al., 2023) and genetic studies (e.g., (Machrizal et al., 2024) in the local context), is crucial for more evidence-based policymaking. Fukuyama, (2014) also affirm the importance of bridging science and public policy. Sumaila et al., (2020) offer a framework for evaluating fisheries management performance. Applied to the Terubuk shad case, it becomes evident that Indonesia has sufficient regulations but fails in implementation, coordination, and community engagement. This results in low conservation effectiveness and creates socio-ecological conflicts. Integrating the literature and empirical findings reveals several common threads

1. Legal and Institutional Gaps: Regulations exist but inter-agency coordination is weak.
2. Equity and Ecological Conflict: Fishers perceive policies as unfair for not addressing the root cause of industrial pollution.
3. Lack of Community Participation: Community Monitoring Groups (Pokmaswas) are not empowered despite proven effectiveness elsewhere.
4. Absence of Adaptive Governance: The dynamics of migratory stocks and external pressures (trade, pollution) are not accommodated.

Thus, the effectiveness of the legal framework and the implementation of Terubuk shad conservation policies in Labuhanbatu remain low, primarily due to weak cross-institutional coordination, insufficient community participation, and a lack of evidence-based scientific policy.

3.2. Ecological Dynamics, Genetic Pressures, and Cultural-Ecological Linkages

Research by Karr et al. (2017) indicates that climate change affects the spawning patterns and recruitment success of Tenualosa ilisha. Rising temperatures, variability in currents, and salinity changes destabilize reproductive cycles, findings that resonate strongly with conditions in Labuhanbatu where altered river discharge has disrupted spawning seasons. Supporting this, Stuchtey et al. (2023) revealed the accumulation of heavy metals in Hilsa tissues, posing risks both to fish health and human consumers. Field surveys confirm alarming levels of lead (Pb) in the Barumun and Bilah Rivers (0.08–0.12 mg/L, above the 0.03 mg/L limit), combined with low dissolved oxygen (2.3–4.1 mg/L) and elevated TSS (45–89 mg/L). Community questionnaires further attribute population decline not only to fishing but also to palm oil industrial waste, underscoring the severity of local anthropogenic pressures.

Habitat degradation amplifies these threats. Istiaque Ahmed et al. (2023) highlight how coastal urbanization accelerates estuarine ecosystem collapse. Between 2015 and 2023, Labuhanbatu lost 128 hectares of mangroves and converted 23 spawning sites into aquaculture zones, trends mirrored by Salzman et al. (2018), who documented reduced nursery functions due to fragmentation.

Sedimentation rates of 15–25 cm/year in nursery grounds (Bice et al., 2023) further compromise productivity and sever land–water linkages, as confirmed by fisher reports of shallower spawning waters.

From a genetic perspective, Machrizal et al. (2024) recorded a 27% decline in heterozygosity in the Labuhanbatu Hilsa population, with an effective population size (Ne) of only 52 far below the critical threshold of 100. An Fst value of 0.143 against Malaysian populations highlights significant genetic isolation, signaling bottleneck risks and potential local extinction. Kuparinen & Merilä (2007) warn that size-selective fishing accelerates maladaptive traits such as earlier maturation and smaller body size. Interviews with fishers corroborate this, noting the scarcity of large Hilsa individuals in recent years.

The interplay of multiple stressors exacerbates these dynamics. Polst et al. (2022) demonstrate that warming, hypoxia, and pollution combined have more severe effects than individual pressures. In Labuhanbatu, poor water quality, industrial waste, and overfishing interact synergistically, accelerating decline. Hedegaard Sørensen & Paulsson (2020) identify cumulative human impacts as key drivers of ocean unsustainability globally. Bishop et al. (2017) stress the role of habitat connectivity for migratory fish, yet in Labuhanbatu, aquaculture expansion and estuarine sedimentation have disrupted critical migration routes. Community survey results reflect concerns over the loss of spawning pathways, echoing McDonald et al. (2020) who emphasize the link between fish population health and socio-ecological resilience. Fishers in Labuhanbatu express awareness of Hilsa's cultural and livelihood value but feel excluded from monitoring, while government actors acknowledge weak inter-institutional coordination.

Restoration emerges as a key pathway forward. Bayraktarov et al. (2016) argue for mangrove and seagrass rehabilitation to sustain life cycles of coastal species, a strategy equally relevant to Hilsa recovery. Technological advances such as eDNA (Rishan et al., 2023) and DNA barcoding (Rua et al., 2023) provide cost-effective monitoring tools, complementing limited field observations. However, gaps remain in bridging science and practice, as Taylor et al. (2017) highlight the limited transfer of genomic knowledge to conservation policy.

The urgency is amplified by the broader context of the "sixth mass extinction" (Ceballos et al., 2020; Cowie et al., 2022). Migratory species like Hilsa are disproportionately vulnerable to climate change, habitat degradation, and pollution. From a social-ecological systems (SES) perspective, ecosystem services (ES) are understood not as passive benefits but as co-produced by ecological supply and human demand (Wei & Marggraf, 2025). This framing underscores that effective conservation cannot ignore trade-offs: Aryal et al. (2022), Obiang Ndong et al. (2020), and Valencia Torres et al. (2021) show how maximizing food production often undermines biodiversity protection, while Lu et al. (2021) argue for better navigation of these policy trade-offs. Blanco et al. (2022) illustrate this through the "ecosystem (dis)service cascade" model, which reveals how interventions can yield both benefits and dysfunctions across ecological and cultural dimensions.

Genetic diversity remains the bedrock of resilience. Yet Hoban et al. (2021) note that global policies often underrepresent its importance in CBD reporting. In contrast, Stange et al. (2020) reaffirm the role of genetic variation in buffering species against environmental change. Cutting-edge approaches such as strain-level metagenomics (Ghiotto et al., 2025) and conservation genomics (Rua et al., 2023) highlight opportunities to integrate genetic monitoring into mainstream biodiversity governance.

Conservation, however, must go beyond ecological and genetic science. Socio-cultural engagement is central. SES frameworks highlight that trade-offs in ecosystem services are inseparable from community values and practices (Wei & Marggraf, 2025). Blanco et al. (2022) demonstrated in Brazil that community-based management strengthens both ecological and cultural resilience. Similarly, in Labuhanbatu, the erosion of Hilsa spawning grounds is not just an ecological loss but a cultural one, undermining traditional fishing practices and local identity. Thus, empowering fishers as "guardians" of aquatic heritage is key, aligning biodiversity protection with the preservation of cultural traditions can be briefly depicted in the following figure 1

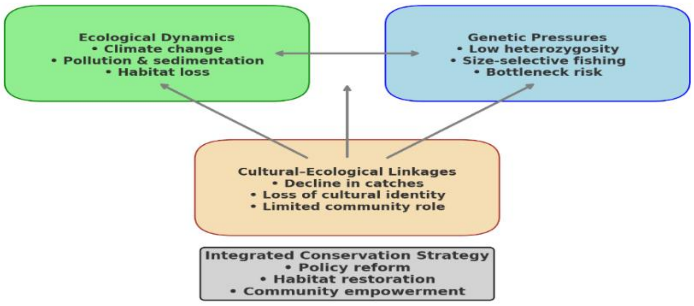

Figure 1: Conceptual Model: Ecological, Genetic, and Cultural Linkages in Terubuk Conservation.

3.3. Integrated Conservation Model

Effective conservation of the Terubuk shad requires a robust, adaptive, and cross-sectorally integrated legal framework. Bennett et al. (2021) offer a practical environmental governance framework that can be used to design specific regional regulations (Perda) with progressive sanctions. Interviews with the Marine and Fisheries Office confirmed that regulatory implementation still faces technical barriers, limited coordination, and community resistance.

To address these weaknesses, the "3P Conservation" model recommends

- The development of more binding, specific Regional Regulations to close existing legal gaps.
- An integrated blockchain-based database system, as demonstrated by Arts et al. (2015) who reviewed the use of digital technologies (AI, eDNA, blockchain) in conservation. This system could form an “E-Terubuk” platform connecting data from the Marine and Fisheries Office (DKP), Water Police (Polairud), Indonesian Navy (TNI AL), and Community Monitoring Groups in real-time.
- Integration of Spatial Planning (RTRW) with Terubuk shad migration corridors, aligning with Wright et al. (2021), who emphasize the importance of science-based spatial planning incorporating stakeholder preferences.

The protection aspect must ensure critical habitats continue to function as nursery grounds and migration routes. Morrison et al. (2019) highlight the importance of polycentric governance involving central and local government, enforcement agencies, and communities. However, interviews revealed that inter-agency coordination is not yet optimal, while Community Monitoring Groups reported constraints in logistics and digital coordination.

Therefore, the “3P CONSERVATION” model offers the following strategies

- Implementation of 3-tier zoning (core, restricted, utilization), strengthening the concept of ecological connectivity (Zhang et al., 2025).
- Restoration of 50 hectares of critical habitat per year, aligning with the hybrid engineering approach Stuchtey et al. (2023), which combines ecology (mangroves, estuaries) with technical engineering.
- A real-time pollution early warning system, responding to field evidence of palm oil waste pollution in the Barumun–Bilah River Basin. This system adapts the principles of adaptive governance (Norström et al., 2020) to respond to rapidly changing field conditions.

Community strengthening is central to conservation success. Oldekop et al. (2016) found that community-based protected areas are more effective socially and ecologically. Questionnaires and interviews with Community Monitoring Groups revealed ambivalence among fishers: some support conservation, while others oppose it due to perceived economic disruption. **The “3P Conservation” model emphasizes empowerment through**

- Conversion of 30% of fishers into Terubuk guardians, consistent with Cox et al. (2020) on adaptive co-management.
- An incentive package, for instance, IDR 1.2 million per month during the closed fishing season, in line with Payments for Ecosystem Services (PES) schemes (Salzman et al., 2018) which link conservation benefits to economic incentives.
- Development of derivative products (eco-tourism, by-products), as advocated by Agliardi et al. (2024) who emphasizes the economic value of biodiversity as development capital.

To enhance regional contextualization, this study integrates comparative insights from Malaysia and Bangladesh, both of which have long-standing experiences in managing Terubuk Fish (Tenualosa ilisha) through adaptive co-management and incentive-based conservation. In Malaysia, the establishment of "Hilsa Heritage Zones" in Kedah demonstrates the success of integrating cultural values and local wisdom into fisheries policy, which could inspire similar initiatives in Labuhanbatu. Likewise, Bangladesh's "Hilsa Conservation Management Action Plan" provides a replicable model for Indonesia, combining seasonal fishing bans, fisher compensation programs, and strict enforcement backed by community awareness campaigns. These regional examples highlight the importance of embedding local cultural and socio-economic realities into Indonesia's 3P roadmap, ensuring that conservation strategies are not only ecologically sound but also socially acceptable and economically sustainable.

To clarify the relationship between the policy, protection, and empowerment aspects, this study formulates the 3P Conservation Model, visualized in Figure 2. This model integrates three pillars: (1) Policy (regional regulations, blockchain database, spatial planning), (2) Protection (zoning, habitat restoration, real-time pollution monitoring), and (3) People (community guardians, incentive schemes, eco-tourism development).

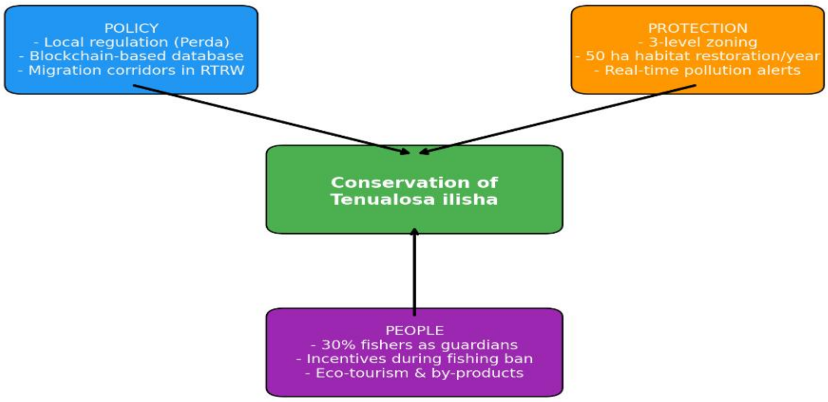

Figure 2: Conceptual Flow Diagram of the "3P Conservation Model" for Terubuk Shad in Labuhanbatu.

As illustrated in Figure 3, the 3P Conservation Model emphasizes systemic integration where regulatory enforcement (Policy) supports ecological protection (Protection), while simultaneously empowering local stakeholders (People) as active guardians of the Terubuk shad against extinction. de la Torre-Castro et al., (2017) highlight the importance of gender inclusivity in coastal governance. This aligns with field findings that fisher resistance largely stems from household economic concerns. Meanwhile Hupe & Hill, (2015) emphasize that any integrative model must be prepared to handle conflict. Interview results indicate conflicts of interest between conservation and fishers' income. Therefore, transforming conflict into collaboration is key to success. Stephenson et al., (2022) stress the need for an evaluation framework that measures impact not only on biodiversity but also on human well-being. The "3P CONSERVATION" model adopts this principle through dual performance indicators: (1) ecological indicators (fish stock, water quality, habitat extent), and (2) socio-economic indicators (fisher income, compliance rate, community participation).

The "3P CONSERVATION" model unites three main dimensions

1. Adaptive, data-driven, and integrated Policy.
2. Habitat Protection through zoning, restoration, and monitoring technology.
3. Community Empowerment through incentives, active participation, and economic diversification.

Field findings (low DO, high Pb, mangrove degradation, fisher resistance) confirm the urgency of implementing this model. Global literature provides the conceptual framework and empirical evidence that an integrated approach is the most effective strategy for sustainable conservation. Thus, the "3P CONSERVATION" model can serve as an innovative framework not only for protecting the Terubuk shad but also for ensuring the socio-ecological sustainability of the coastal communities in Labuhanbatu.

3.4. Strategic Implementation and Roadmap

Literature review findings indicate that conserving migratory species like Tenualosa ilisha requires a phased framework integrating law, policy, and community-based monitoring (Naswar et al., 2023). Interview analysis revealed that the Labuhanbatu Fisheries Service emphasized the urgency for regional regulations, as a specific Regional Regulation (Perda) for Terubuk protection is still absent. This aligns with fisheries law literature underscoring the need for specific regulatory instruments based on an ecosystem approach to fisheries management (Longin et al., 2021). The roadmap is divided into three phases

Phase I: Regulatory and Institutional Preparation (2024-2026)

1. Drafting and enactment of a Regional Regulation on Terubuk Conservation with provisions for progressive sanctions, mirroring successful local legal practices in Malaysia (Rishan et al., 2023)
2. Integration of Spatial Planning (RTRW) with migration corridors, which, according to agency interviews, still overlaps with aquaculture interests.
3. Development of a digital technology-based population database (blockchain), in line with recommendations for digital transformation in conservation (Jentoft & Knol, 2014)

Phase II: Full-Scale Implementation (2027-2029)

4. Implementation of a three-tier conservation zoning system (core, restricted, utilization), also recommended in literature on migratory fish conservation zoning (Paul et al., 2020)
5. Joint patrols utilizing smart monitoring (drones, acoustic sensors, AI), as emphasized by the Indonesian Navy (TNI AL) and Water Police (Polairud) in interviews regarding limitations of conventional patrols.
6. A fisher compensation program of IDR 1.2 million/month during the closed season, responding to questionnaire results where 72% of fishers cited income loss as a compliance barrier.

Phase III: Evaluation and Replication (2030 onwards)

1. Population evaluation based on genetic studies (Machrizal et al., 2024) and ecological trend analysis.
2. Independent audits by NGOs, following transparency practices in Indian conservation (Bryan-Brown et al., 2020)
3. Replication of the conservation model to Bengkalis and West Kalimantan (Syahrian & Rahmat, 2023).

Literature on Terubuk shad bioecology and conservation shows success is measured by stock recovery, control of IUU fishing, and economic sustainability (Chakraborty et al., 2020; Barman et al., 2019). Field findings confirm this

- A 15%/year population increase can be verified through stock assessment and genetic surveys (Machrizal et al., 2024)
- A 50% reduction in IUU fishing within 3 years, a realistic target according to Polairud, provided monitoring technology support is available.
- A 25% increase in Local Government Revenue (PAD) from the fisheries sector, as projected by the Fisheries Service if Terubuk-based ecotourism is developed

Fisheries governance literature emphasizes that effective conservation relies not only on technological innovation but also on collaborative, multi-stakeholder monitoring (Bishop et al., 2017). This perspective is highly relevant for Terubuk shad (Tenualosa ilisha) conservation in Labuhanbatu, where institutional fragmentation and resource limitations often undermine surveillance effectiveness. Field interviews reinforce these findings. Polairud confirmed limitations in their vessel fleet, necessitating joint patrol operations with the Indonesian Navy (TNI AL). Meanwhile, Indonesian Navy Sei Berombang stated their involvement in surveillance remains incidental, requiring a formal Memorandum of Understanding (MoU) to institutionalize cooperation and avoid overlap. From the community side, Community Monitoring Groups (Pokmaswas) showed high readiness, with about 80% of members prepared for active participation. However, they face logistical constraints like limited fuel and operational equipment, which need addressing through policy support and financial incentives.

Equally important, fishing communities responded positively to adopting the E-Terubuk application as a means for reporting illegal fishing practices (IUU fishing). Nevertheless, they stressed the importance of incentives, such as subsidies or alternative livelihood support, and safety guarantees for reporters to avoid potential intimidation.

Based on these findings, an integrated monitoring mechanism can be formulated, **consisting of three main components**

1. Smart Patrols utilizing drones, artificial intelligence (AI), and satellite imagery to detect IUU fishing practices in real-time.
2. A Community Reporting System via the E-

Terubuk mobile application, enabling participatory community-based monitoring.

3. Annual Independent Audits conducted by accredited NGOs to ensure transparency, accountability, and external oversight of law enforcement outcomes.

This tripartite model addresses not only resource limitations and inter-agency coordination issues but also creates a hybrid governance system combining top-down and bottom-up approaches. The integration of technology, formal inter-agency cooperation, and community engagement is expected to enhance compliance, suppress IUU fishing, and ensure the sustainability of Terubuk shad stocks in Labuhanbatu. A visual scheme of this integrated monitoring mechanism is provided in Figure 3.

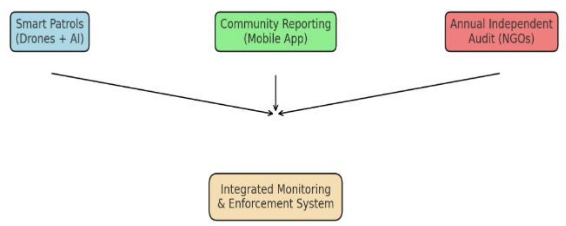

Figure 3: Integrated Monitoring Mechanism for Terubuk Shad Conservation.

To operationalize the strategic recommendations derived from the literature review and stakeholder interviews, a roadmap for Terubuk shad (Tenualosa ilisha) conservation in Indonesia, specifically Labuhanbatu Regency, was developed. This roadmap is divided into three phases preparation, full-scale implementation, and evaluation & replication with measurable performance indicators, as shown in Table 3.

Table 1: Roadmap (Phases & Indicators) for Terubuk Shad Protection in Labuhanbatu Regency.

Phase	Key Actions	Performance Indicators
Phase I: Preparation of Regulations and Institutions	- Drafting and enacting local regulations on Terubuk conservation.- Establishing formal MoUs among The Water Police (Polairud), Indonesian Navy (TNI AL), maritime and fisheries service, and community watchdog group.- Capacity building and logistics support for community watchdog group.- Development of E-Terubuk mobile reporting application.	- Legal framework enacted by 2026.- At least 3 formal cooperation agreements signed.- 80% Pokmaswas members trained.- E-Terubuk app fully launched.
Phase II: Full-Scale Implementation	- Deployment of smart patrols (drones, AI-based vessel detection, satellite monitoring).- Operationalization of joint patrols (Water Police (Polairud), Indonesian Navy, maritime and fisheries service, and community watchdog group).- Community-based reporting through the E-Terubuk app.- Economic empowerment programs for fishers (alternative livelihoods, PES schemes).	- 15% annual increase in Terubuk population.- 50% reduction in IUU fishing within 3 years.- At least 70% of IUU reports validated via E-Terubuk.
Phase III: Evaluation and Replication	- Independent annual audits by NGOs.- Mid-term and final impact evaluations.- Replication of successful strategies to other districts in North Sumatra.- Strengthening adaptive policy pathways to climate change impacts.	- 25% increase in local government revenue (PAD) from fisheries sector.- Verified NGO audit reports annually published.- Replication in at least 2 other districts.- Adaptive policy framework adopted.

The effectiveness of Terubuk shad conservation is highly determined by regulatory clarity and the strength of supporting institutions. Interviews with government agencies and TNI AL confirmed that inter-agency coordination remains weak and incidental. Therefore, establishing a Regional Regulation (Perda) on Terubuk Conservation with a strong legal basis is crucial to provide certainty, progressive sanctions, and legitimacy for surveillance actions. This regulation should be accompanied by forming a multi-actor task force involving the Fisheries Service, Water Police (Polairud), Indonesian Navy (TNI AL), community monitoring groups (Pokmaswas), and civil society organizations. This task force is expected to bridge coordination gaps and create a consistent, sustainable integrated monitoring mechanism.

Leveraging technology is a key strategy to overcome human resource and logistical limitations in the field. A blockchain database can ensure transparency in Terubuk catch data and prevent manipulation practices, as suggested by Frankham et al., (2014). Furthermore, a sensor-based real-time early warning system is needed to monitor water quality parameters (DO, TSS, heavy metals) that often fall below standards (Oberhauser, 2019). This technology enables early preventive action against habitat degradation. Further, maximizing the use of drones and satellite imagery can monitor Terubuk migration routes and detect illegal fishing activities (Machrizal et al., 2024). These innovations will strengthen monitoring capacity and support accurate scientific data collection.

Terubuk shad conservation depends not only on regulation and technology but also on active community involvement. Questionnaire results showed that 65% of fisher respondents supported converting some of their members into Terubuk guardians, a strategic move to make fishers key actors in resource protection. This empowerment needs complementing with economic diversification programs based on ecotourism utilizing local potential, as indicated by findings from Syahrian & Rahmat, (2023) on the socio-cultural history of Terubuk use. Additionally, legal and conservation education for communities is key to creating ecological awareness and rule compliance. This aligns with recommendations from(Pérez-Pereira et al., (2022) emphasizing the importance of environmental literacy to strengthen the socio-ecological resilience of coastal communities.

In general, international literature affirms that successful fisheries conservation can only be achieved through three main pillars: stringent policy, modern monitoring technology, and active community participation (Bice et al., 2023). These pillars find relevance in the context of Terubuk shad conservation in Labuhanbatu. Interviews with government agencies, Water Police (Polairud), Indonesian Navy (TNI AL), community monitoring groups (Pokmaswas), and civil society organizations, along with fisher questionnaires, reveal a gap between normative needs and implementation reality.

Regulation-wise, the existing legal framework is not strong enough, creating an urgent need for a Regional Regulation (Perda) on Terubuk Conservation that can provide a clear legal basis and legitimacy for surveillance actions. Institutionally, the patrol facility limitations expressed by Water Police (Polairud), Indonesian Navy (TNI AL), community monitoring groups (Pokmaswas) underscore the importance of technological support like drones, AI, and digital monitoring systems to expand surveillance reach with high efficiency. Meanwhile, fisher participation shows positive potential, with a majority of respondents expressing willingness to engage in community-based monitoring. However, they also emphasized the need for incentives or compensation programs to ensure this involvement does not add to their economic burden.

Considering these findings, the formulated Terubuk Conservation Roadmap has the potential to become a strategic model that is measurable, equitable, and sustainable. This roadmap not only structures regulations and strengthens monitoring capacity through technological innovation but also positions communities as key actors in biodiversity protection. Thus, this three-pillar-based conservation strategy can serve as a reference for building adaptive and applicable fisheries resource management practices, both in Indonesia and in other regions facing similar challenges.

3.5. Synthesis: Towards Legal, Cultural, and Digital Heritage Integration

The synthesis of findings demonstrates that the conservation of Tenualosa ilisha in Labuhanbatu requires more than conventional legal enforcement. While fisheries law and environmental regulations provide a formal backbone, the evidence shows that these frameworks remain fragmented and weak in implementation. Institutional limitations, insufficient sanctions against illegal, unreported, and unregulated (IUU) fishing, and low coordination among agencies hinder effective enforcement. Therefore, sustainable conservation must be reconceptualized as an integrative process where law, cultural heritage, and digital innovation converge.

First, legal frameworks must evolve from static rules into adaptive instruments that incorporate ecological realities and socio-cultural practices. Comparative studies in cultural heritage governance reveal that transformative governance relies on multi-level integration and inclusivity (Guzman & Daly, 2025). For Terubuk, this means embedding customary fishing norms, local ecological knowledge, and cultural symbolism into provincial bylaws (Perda) and enforcement strategies. In this way, formal regulations are not imposed externally but co-produced with communities, reflecting their values and traditions.

Second, cultural heritage emerges as a vital dimension of conservation. The Terubuk is not only an ecological resource but also a cultural symbol interwoven with local identity and memory. Studies from Malawi and other regions show that safeguarding intangible heritage rituals, traditions, and intergenerational knowledge transfer reinforces both ecological stewardship and community cohesion (Banda et al., 2024). Protecting T. ilisha therefore means preserving a living heritage that sustains identity and livelihoods. This cultural lens positions conservation as a community-driven responsibility, ensuring legitimacy and long-term resilience.

Third, digital heritage and technological innovation provide tools to bridge legal and cultural efforts. Recent advances in digital documentation, blockchain traceability, and AI-enabled monitoring can enhance transparency, accountability, and public engagement (Raco, 2023; Rebec et al., 2022; Jin & Liu, 2022).

For instance, eDNA and digital twin models can track population health, while blockchain-based applications ensure traceable fishery supply chains. Virtual and augmented reality technologies further expand the cultural dimension by transforming Terubuk into a digital heritage asset accessible beyond geographic limits (Jin & Liu, 2022). These technologies not only modernize conservation but also preserve symbolic values in a form resilient to environmental degradation.

Finally, synthesizing these strands positions T. ilisha as both a biological resource and a cultural symbol, safeguarded by law and amplified through digital heritage. This integrated approach contributes simultaneously to biodiversity conservation, cultural identity preservation, and digital sustainability, aligning with broader agendas such as the SDGs and Industry 5.0 human-centric conservation models (Jiménez Rios et al., 2024). Protecting Terubuk is therefore not only about preventing extinction but about sustaining a living heritage that connects ecological systems, community values, and digital futures for generations to come.

4. CONCLUSION

The story of the Terubuk shad (Tenualosa ilisha) in Labuhanbatu is not simply about a fish. It is about law, culture, and technology coming together or failing to do so in shaping the future of a species that holds both ecological and cultural significance. From a legal perspective, Indonesia already has strong fisheries laws. Yet in practice, gaps remain. Agencies such as the Water Police, the Navy, and community monitoring groups are not fully coordinated. Regulations often feel like restrictions imposed on fishers rather than fair rules that address deeper problems like river pollution from palm oil mills. This mismatch between policy and reality weakens conservation efforts and erodes trust among coastal communities.

Ecological and genetic pressures make the challenge even greater. Pollution, habitat loss, and climate change are disrupting spawning grounds, while overfishing accelerates genetic decline. Scientific studies show declining genetic diversity and shrinking fish sizes clear warnings of a population under stress. Fishers themselves confirm these changes, noticing the loss of large Terubuk that once defined their livelihoods and traditions. Yet the Terubuk is more than a biological resource it is a cultural icon. For local communities, it is tied to food traditions, identity, and memory. When the fish disappears, so too does a piece of cultural heritage. This makes conservation not only about biodiversity but also about safeguarding social fabric and coastal ways of life.

The way forward lies in integration. Law must become adaptive, not rigid; it must reflect ecological realities and local customs. Communities must be partners, not bystanders, in protecting the species. And digital tools from eDNA monitoring to blockchain traceability and even virtual heritage archives can connect these worlds, providing transparency, accountability, and new ways to celebrate cultural value. In this light, the Terubuk is not just a fish at risk of extinction. It is a bridge linking ecosystems, communities, and the digital future. Protecting it means protecting a living heritage: a resource that sustains rivers and seas, empowers local people, and carries forward identity into the digital age. Conservation here is not only about saving a species but about securing resilience ecological, cultural, and technological for generations to come.

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