

Ecological Restoration and Rehabilitation of the Petagas River System in Malaysian Borneo

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UCCRN Case Study Docking Station (2025)
DOI: 10.7916/nbda-2a50

Keywords	Biodiversity, Sustainability, Ecosystem restoration, Climate change, Coastal River
City Population	489,794
City Area	351 km ²
City GDP	RM83.2 billion
Climate Zone	Am (tropical monsoon)
ARC3.3 Linkage	Nature-based Solutions Element



Figure 1. Petagas River (Sungai Petagas), Putatan, Sabah

Introduction. The importance of coastal river systems in Malaysian Borneo cannot be overemphasized. Generally, these resources are home to a repository of biodiversity and provide many ecosystem services such as aquatic food, drinking water, irrigation, and recreation, and help in mitigating the effects of climate change. Petagas river is in the district Putatan (Figure 1) on the west coast of Sabah, Malaysia, and is surrounded by many settlements. Historically, this vital body of water has seen an intense human interaction through overfishing, navigation, and discharge of untreated household waste and nutrients. Obviously, these activities have impacted the ecosystem of the river and undermined the services it provides. Ecological restoration of this body of water is the main strategy for regaining biodiversity and increasing the provision of ecosystem services.

Absence of scientific data was a major constraint in developing a comprehensive knowledge-based plan of action. The local community treated it as a ‘dead river’ mainly because of loss of fishing grounds and uncontrolled disposal of waste as indicated by high ammonia concentration (4.02 mg/L to 6.72 mg/L) at the downstream, suggesting high anoxic conditions (Maidin et al., 2014).

Accurate assessment of human impacts on riverine ecosystems or other habitats requires knowledge of baselines that can serve as reference conditions (Gatti et al., 2015). For a river that has been under continuous changes it was difficult to define the natural state and understand the pristine condition against which to measure the alterations. However, a descriptive historical information obtained from the community and individual experience of researchers can help in gaining insights into what the ecosystem should look like rather than how the environment was without human impacts for the purpose of ecosystem assessment and enhancement (McClenachan et al., 2012; Gatti et al., 2015). This case study represents collaborative efforts of scientists, community, and local governance frameworks in the river ecosystem restoration through a novel and cost-effective approach.

Innovative Initiative. Environmental care and biodiversity restoration were blended to breathe life into this human-altered and highly degraded river system (Figures 2, 3). The project entailed establishing biodiversity links and seeking the cooperation of local communities in conservation. Ecological restoration has a broad scope and many different strategies to achieve it, but it is a plausible way for reversing biodiversity declines and rebuilding ecosystem services (Bullock et al., 2011). The challenge is to devise a practical strategy that does not require large budgetary allocations.



Figure 2. *Sampling site in Petagas River.*
Photo credit: Nazia Abdul Kadar



Figure 3. *A shrimp stock enhancement area in Petagas River.*
Photo credit: Nazia Abdul Kadar

This ecodevelopment project commenced with the ranching of about 20,000 post-larval stages of giant freshwater shrimp (*Macrobrachium rosenbergi*) in 2012 (Kian et al., 2012), followed by further releases amounting to about 40,000 specimens until 2015. This species is known to thrive on available resources in the river and thus, can support depleted populations of species of higher trophic levels foraging on it. The carrying capacity of river ecosystems depends on abiotic and biotic factors. Availability of essential needs such as food, water and shelter are deciding factors in the survival and growth of released individuals. As pointed out earlier, the river has been a site of household waste disposal for too long and has a large deposit of organic waste. It can sustain the population of shrimp that consumes organic matter and detritus in addition to plankton and fragments of macrophytes and dead invertebrates. This mode of life makes them an essential component of the food chain by not only reducing the build-up of organic matter but also unlocking and recycling the essential nutrients for the operation of biogeochemical cycles of carbon, nitrogen, and phosphorus. Detritivorous habit and

primary consumer status of *Macrobrachium* make it a low trophic chain species that supports secondary consumers and successively higher trophic levels to contribute to the energy cycle of the ecosystem. Due to this and probably other attributes, no negative impacts from farming or ranching of this species have so far been reported (FAO, 2009; Santos et al., 2016).

Tropical conditions and food abundance offer year-long growth opportunities to the shrimp. *Macrobrachium* requires ecological corridors for unhindered movement for its migratory lifestyle, feeding, breeding and larval development. At the time of breeding, gravid females in the river migrate downstream into estuaries where eggs hatch out into free-swimming larvae and undergo metamorphosis. Subsequently, they transform into post-larvae that migrate upstream where freshwater conditions prevail and where these young stages assume a more benthic mode, often walking at the substratum, submerged objects and even stones along the river edges (FAO, 2009). Restoration of such corridors (often termed as 'blue-green' corridors) is challenging in urban areas that are associated with a high density of human population and intense business activities, and where the river mouth is drastically altered by reclamation. Scientists resolved this problem by sampling wild stocks from the natural population, growing them in the hatchery to bloodstock stage and performing captive breeding in brackish water in the tanks. The larvae were grown to a post-larval stage and reared in a freshwater medium. Juveniles were then released into the river. By this way, their brackish water phase of life was maintained in the hatcheries before ranching into the middle reaches of the river outside the influence of saline conditions.

Being an indigenous species, *Macrobrachium* is adapted to local habitats and turbid conditions, and poses no risk of introducing new pathogens into the natural population (Bridger and Gaber, 2002). Furthermore, it meets the local acceptance, which is one of the sustainability conditions, besides the convenience of sourcing wild stocks for captive breeding to prevent loss of genetic diversity (Santos et al., 2016). The ongoing investigations will be able to yield data that will provide a basis for decisions regarding the transition of the harvest-type of shrimp ranching to recruit-type. Presence of gravid females of the released stocks suggested that recruitment was taking place but whether it has reached a level that can sustain the population despite fishing pressure is uncertain at this stage. For the sake of genetic diversity of the released stocks the specimens of captive shrimp need to be sourced from the wild before closing the breeding cycle to prevent inbreeding depression. Compliance with the Code of Conduct for Responsible Fisheries developed by the Food and Agriculture Organization (FAO, 2009) will ensure that the ranching is done in a responsible way and the capture fisheries remain sustainable.

While ranching involved a single low trophic chain species, the objective was to initiate a broader ecological restoration for the revival of natural processes and the renewal of ecosystem services over time. Main considerations that weighed heavily in this initiative were availability of technical knowledge, financial support, logistical assistance, feasibility, and participation of local communities and government institutions.

Post-Ranching Monitoring. Detailed observations were made on Petagas river following the shrimp releases. Maidin et al. (2017) carried out comprehensive studies that involved the sampling of 539 specimens over a period of September 2013 - May 2015. Key findings of these investigations are that the catch per unit effort was positively correlated with the stocking rate ($R^2=0.89$) and the specimens caught from the river showed a genetic sequence similar to the released stock (genetic distance = 0.00 - 13.8%). This data suggested success of the stock enhancement effort and adaptation of the hatchery-produced specimens in the river ecosystem to survive, grow and mature. The program was initially intended to be a type of ranching where the seed produced in hatcheries is released into a natural body of water and allowed to grow and breed to enhance the population until such time that catch statistics suggest recruitment capacity of the released stocks.

Investigations were also focused on biodiversity of the river ecosystem. In this context, Nazia et al. (2020) conducted monthly observations from October 2019 to March 2020 to document the fish diversity in the river. A total of 615 fish specimens were collected. Of the 21 species identified, 19 are generally distributed in brackish water and 2 are known to occur in freshwater bodies. *Arius maculatus* formed 74.6% of the total catch. The other species from this order was *Hexanematichthys sagor*. The rest of the species caught belonged to the orders Perciformes (8.6%), Elopiformes (7.3%), Clupeiformes (3.7%), Mugiliformes (3.3%), Cypriniformes (1.8%) and Tetraodontiformes (0.65%). Change in the river quality is also evident from the establishment of plankton communities. The phytoplankton which form the foundation of the aquatic trophic web were represented by the genera *Coscinodiscus*, *Pleurosigma*, *Bacteriastrum*, *Thalassiothrix*, *Rhizosolenia*, *Skeletonema*, *Ceratium*, *Asterionella*, *Oscillatoria*, *Scenedesmus*, *Coelastrum* and *Euglena* (Maidin et al., 2014).

Adaptation to Climate Change. The Petagas river is vitally important to the surrounding indigenous communities as it provides income through fishing. However, the water quality and habitat have been undergoing degradation due to direct rubbish dumping and other anthropogenic activities along the river. Management of the river basin is necessary for restoring the functioning of its ecosystem and the community's resilience. Climate change reduces the natural ability of river systems to self-mitigate (Palmer et al., 2008). These ecosystems have the potential to absorb climate-related stress, but strategic interventions are needed to restore and maintain their essential environmental features (Thieme, 2021). In this context, integration of knowledge from diverse perspectives and prioritizing nature-based solutions can produce long-term benefits. Application of the most appropriate solution can be critical to tackling climate risks and driving resilience.

This case study also draws attention to the need for innovative methods of integrating biodiversity into the natural capital of coastal rivers and the latter into decision-making. The findings demonstrate how a collective commitment of stakeholders can produce meaningful results in terms of climate resilient riverine ecosystems, communities, and economies. Further investments in biomimicry designs

inspired by nature and living systems can offer a variety of solutions to accelerate river ecosystem restoration.

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Acknowledgments

We thank Dr. Adeb Qaid, Kingdom University, for providing comments for improving the article.

Additional Data

- **Population Density:** 1,492 people/km²
 - **Gross National Income (GNI):** 15,020 USD (Higher-Middle Income) [2023]
 - **Gini Coefficient:** 36.1 [2023]
 - **Human Development Index (HDI):** 0.728 (High) [2025]
 - **Type of Climate Intervention:** Hybrid (Both Adaptation and Mitigation)
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