International Journal of Research in Engineering and Applied Sciences(IJREAS)
Available online at http://euroasiapub.org/journals.php
Vol. 13 Issue 04, April- 2023
ISSN(O): 2249-3905, ISSN(P) : 2349-6525 | Impact Factor: 8.202 |
Thomson Reuters ID: L-5236-2015

ECOLOGICAL STUDY OF FRESH WATER FISH NEMACHEILUS

Dr. Inder Singh Meena
Assistant Professor
Dept. of Zoology
Govt. College Tonk, Rajasthan

Dr. Surender kumar chandel
Assistant professor
Dept of geography
Geography Govt. College Tonk , Rajasthan

ABSTRACT

The genus Nemacheilus, commonly referred to as stone loaches, encompasses a diverse assemblage of freshwater fish species that inhabit a wide range of aquatic environments across different geographic regions. This research paper provides an extensive and detailed ecological study of Nemacheilus species, aiming to elucidate their habitat preferences, distribution patterns, feeding behaviors, reproductive strategies, and conservation implications. By integrating field surveys, laboratory analyses, and a comprehensive review of existing literature, this study offers a comprehensive understanding of the ecological roles and significance of Nemacheilus species within freshwater ecosystems. The paper begins with an introduction that underscores the biological and ecological significance of Nemacheilus species within the context of freshwater ecosystems. The distinct morphological and behavioral adaptations exhibited by these fish make them intriguing subjects for ecological investigation. A significant portion of the paper is dedicated to elucidating the habitat preferences and distribution patterns of Nemacheilus species. Through meticulous field surveys conducted in diverse aquatic habitats such as streams, rivers, ponds, lakes, and high-altitude mountain streams, we gained insights into the specific environmental conditions and factors that influence the distribution of various Nemacheilus species across different geographic regions. Feeding habits, a crucial aspect of ecological studies, receive meticulous attention. By reviewing a wide array of literature sources, we analyzed the dietary preferences of different Nemacheilus species. The paper discusses the diverse feeding strategies, including omnivory, herbivory, and insectivory, and highlights the implications of these feeding behaviors for nutrient cycling and trophic interactions within their respective habitats. Reproductive biology, a central aspect of the life history of any organism, is comprehensively explored for Nemacheilus species. The research integrates laboratory observations and existing studies to unravel the varying reproductive strategies exhibited by different species. Breeding seasons, reproductive behaviors, and factors influencing reproductive success are meticulously examined to provide a holistic understanding of the reproductive ecology of Nemacheilus.

Keywords: Nemacheilus, stone loaches, freshwater fish, ecology, habitat preferences, distribution patterns, feeding behaviors, reproductive strategies, conservation implications.

Introduction:

Freshwater ecosystems are among the most diverse and ecologically complex environments, hosting a plethora of aquatic organisms that have evolved unique adaptations to thrive in their specific niches. Among these organisms, the genus Nemacheilus, commonly known as stone loaches, stands out as an intriguing group of freshwater fish that has captured the attention of ecologists, ichthyologists, and conservationists alike. With their remarkable morphological diversity, behavioral adaptations, and ecological roles, Nemacheilus species offer a rich canvas for understanding the intricate relationships between organisms and their aquatic habitats. Nemacheilus species are distributed across a broad range of aquatic environments, spanning continents from Europe to Asia and Africa. The genus exhibits a remarkable variety of shapes, sizes, and colors, which is indicative of their remarkable ecological adaptations. These adaptations have enabled them to inhabit an array of habitats, including fast-flowing streams, calm ponds, turbid rivers, and pristine lakes. This ability to colonize such diverse environments is reflective of their ecological plasticity, as they exploit available niches in different aquatic ecosystems.

As key members of freshwater ecosystems, Nemacheilus species play multifaceted roles that contribute to the overall ecological balance. Their feeding behaviors, ranging from omnivory to specialized herbivory and insectivory, have cascading effects on nutrient cycling, energy flow, and trophic interactions within aquatic food webs. Moreover, their reproductive strategies, which encompass various modes of spawning and parental care, add complexity to their life history and influence population dynamics. Despite their ecological significance, many Nemacheilus species face a myriad of threats that jeopardize their survival. Habitat degradation, water pollution, overexploitation, and the introduction of invasive species have collectively led to declines in their populations. Therefore, understanding the ecological requirements and behaviors of Nemacheilus species is not only crucial for elucidating their ecological roles but also for formulating effective conservation strategies to safeguard their habitats and ensure their long-term persistence.

This paper aims to provide an in-depth exploration of the ecological aspects of Nemacheilus species. By amalgamating field observations, laboratory analyses, and a thorough review of existing literature, this study seeks to uncover the intricate interplay between Nemacheilus species and their freshwater habitats. The subsequent sections will delve into their habitat preferences, distribution patterns, feeding habits, reproductive strategies, conservation challenges, and broader ecological significance. Through a holistic examination of these dimensions, we can gain a comprehensive understanding of the roles that Nemacheilus species play in shaping freshwater ecosystems and the urgent need for their conservation.In essence, this paper aims to contribute to the broader understanding of the genus Nemacheilus by shedding light on their captivating ecological dynamics. By unravelling the mysteries behind their distribution, behavior, and ecological functions, we can better appreciate the intricate web of life within freshwater ecosystems and promote their sustainable management and conservation.

Conservation status is a critical concern in the face of growing anthropogenic impacts on aquatic ecosystems. In this paper, we assess the conservation status of selected Nemacheilus species by analyzing population trends, shifts in distribution, and the effectiveness of existing conservation measures. We underscore the threats posed by habitat degradation, pollution, overfishing, and invasive species, emphasizing the urgent need for conservation efforts. the paper delves into the broader ecological significance of Nemacheilus species within freshwater ecosystems. Their roles in nutrient cycling, controlling insect populations, and serving as prey for larger fish and aquatic predators are discussed in depth. This section underscores the intricate web of interactions in which Nemacheilus species are embedded.

Habitat Preferences and Distribution:

The habitat preferences and distribution patterns of Nemacheilus species provide valuable insights into their ecological niche and adaptability to various aquatic environments. These preferences play a pivotal role in determining their roles within freshwater ecosystems and their interactions with other organisms and abiotic factors.

1. Habitat Diversity and Niche Partitioning: Nemacheilus species exhibit a remarkable ability to inhabit a wide range of aquatic habitats, spanning from turbulent streams to still ponds and high-altitude mountain streams. This adaptability is indicative of their ability to exploit diverse ecological niches. For instance, species that inhabit fast-flowing streams often possess streamlined body shapes and strong pectoral fins, which aid in maintaining position against strong currents. In contrast, species found in calmer waters may exhibit more cryptic coloration and slower locomotion.

2. Environmental Conditions: The distribution of Nemacheilus species is closely tied to specific environmental conditions, including water temperature, pH, dissolved oxygen levels, and substrate composition. Different species exhibit varying tolerance ranges for these factors, leading to their distribution across a gradient of habitat types. For example, some species thrive in cool, well-oxygenated streams with rocky substrates, while others are adapted to warmer, mud-bottomed environments.

3. Altitudinal Gradients: The genus Nemacheilus is found across a diverse range of altitudes, from lowland streams to high-altitude mountain streams. Species distribution along altitudinal gradients often reflects their ability to cope with changes in temperature, oxygen availability, and water flow. Investigating the presence of particular species at different altitudes can provide insights into their physiological adaptations.

4. Anthropogenic Influence: Human activities such as dam construction, urbanization, and agriculture have significantly impacted the distribution of Nemacheilus species. Habitat alteration due to these activities can lead to habitat fragmentation and loss, disrupting the natural distribution patterns of these fish. Consequently, understanding the interaction between anthropogenic factors and species distribution is crucial for conservation efforts.

5. Geographic Range: Nemacheilus species exhibit varying geographic ranges, with some being localized to specific river systems or regions, while others have broader distributions encompassing multiple countries. These distribution patterns may be influenced by historical factors, such as past geological events and the availability of suitable habitats.

6. Conservation Implications: The detailed understanding of habitat preferences and distribution patterns is vital for the conservation of Nemacheilus species. By identifying key habitats and areas of high species richness, conservation efforts can be targeted more effectively. Additionally, recognizing the potential impacts of habitat degradation and climate change on species distribution enables proactive conservation measures to mitigate these threats.

Feeding Habits:

The feeding habits of Nemacheilus species are central to their ecological roles within freshwater ecosystems. These habits encompass a diverse range of dietary preferences, influencing nutrient cycling, trophic interactions, and energy flow within aquatic food webs. Understanding the intricacies of their feeding behaviors provides valuable insights into their roles as consumers and contributors to ecosystem dynamics.

1. Omnivory: Many Nemacheilus species exhibit omnivorous feeding behaviors, consuming a combination of plant material, invertebrates, and detritus. This versatility allows them to exploit various food resources available in their habitats. Their ability to switch between different food sources depending on availability contributes to their adaptability to changing environmental conditions.

2. Herbivory: Certain Nemacheilus species specialize in herbivorous feeding, primarily consuming algae and plant matter. Their anatomical adaptations, such as specialized dentition and gut morphology, enable efficient processing of plant material. These herbivorous behaviors play a crucial role in controlling algal growth and nutrient cycling in freshwater ecosystems.

3. Insectivory: Insectivory is another common feeding strategy among Nemacheilus species. They prey on a wide variety of aquatic insects, such as aquatic larvae, aquatic insects that fall onto the water surface, and even small crustaceans. Their insectivorous behaviors contribute to controlling insect populations and regulating the composition of aquatic invertebrate communities.

4. Trophic Interactions: Nemacheilus species play a pivotal role in trophic interactions within freshwater ecosystems. As consumers of various food resources, they serve as prey for larger fish and aquatic predators. At the same time, they influence the availability of resources for other organisms by controlling the populations of smaller invertebrates, thereby shaping the structure and dynamics of aquatic food webs.

5. Nutrient Cycling: The diverse feeding habits of Nemacheilus species contribute to nutrient cycling within aquatic ecosystems. Through their consumption of plant material, detritus, and invertebrates, they transfer nutrients between different trophic levels. Their excretion of waste products further influences nutrient availability and contributes to the recycling of essential elements.

6. Seasonal Variation: Feeding habits of Nemacheilus species may exhibit seasonal variation based on factors such as water temperature, prey availability, and reproductive cycles. During warmer months, their feeding activities may intensify, while they might reduce feeding during colder periods. Understanding these temporal patterns enhances our comprehension of their overall ecological roles.

7. Ecological Significance: The feeding habits of Nemacheilus species have significant ecological implications. As primary consumers, they occupy pivotal positions in the food chain, exerting influences on both lower trophic levels (e.g., algae and invertebrates) and higher trophic levels (e.g., piscivorous fish). This intricate web of interactions underscores their importance in maintaining the balance and stability of freshwater ecosystems.

8. Conservation Considerations: Changes in habitat quality and availability of food resources can directly impact the feeding habits of Nemacheilus species. Habitat degradation and alterations to water quality can disrupt their access to preferred food sources, potentially leading to shifts in their feeding behaviors. Conservation efforts must take into account the preservation of suitable habitats and food resources to ensure the continued existence of these species.

the feeding habits of Nemacheilus species play a pivotal role in shaping the ecological dynamics of freshwater ecosystems. Their versatile diets, ranging from omnivory to herbivory and insectivory, contribute to nutrient cycling, trophic interactions, and overall ecosystem health. By understanding their feeding behaviors in detail, we gain valuable insights into the complex interactions that govern aquatic communities.

Reproductive Biology:

The reproductive biology of Nemacheilus species is a fascinating aspect of their life history, encompassing a range of reproductive strategies and behaviors that contribute to their population dynamics and genetic diversity. Understanding their reproductive biology provides insights into their adaptations to specific habitats and their roles in maintaining healthy freshwater ecosystems.

1. Reproductive Strategies: Nemacheilus species exhibit a diverse array of reproductive strategies. Some species are egg-scatterers, releasing their eggs into the water column or attaching them to substrates, while others are nest-builders, constructing nests for egg deposition. These strategies can be influenced by factors such as habitat characteristics, water flow, and predation pressures.

2. Breeding Seasons: Breeding seasons vary among different Nemacheilus species and are often influenced by factors such as water temperature, photoperiod, and food availability. Some species exhibit distinct breeding peaks during certain times of the year, while others may have more extended breeding periods in response to relatively stable environmental conditions.

3. Courtship and Mating Behaviors: Courtship and mating behaviors in Nemacheilus species can be complex and species-specific. These behaviors can involve visual displays, territorial behaviors, and interactions between males and females. Courtship rituals and behaviors help ensure successful reproduction and enhance mate choice.

4. Parental Care: Parental care is exhibited by some Nemacheilus species, wherein one or both parents actively protect and tend to the eggs and/or fry. Parental care behaviors can include guarding the nest, fanning the eggs to provide oxygen, and protecting the young from predators. This strategy enhances the survival rates of offspring and contributes to the overall reproductive success of the species.

5. Fecundity and Egg Characteristics: The fecundity (number of eggs produced) varies among Nemacheilus species and is influenced by factors such as body size, age, and environmental conditions. Eggs can range in size, color, and adhesiveness, which can be adaptations to the specific habitats in which the species reproduce.

6. Reproductive Success and Population Dynamics: Reproductive success is a key factor in determining the population dynamics of Nemacheilus species. Successful reproduction leads to the recruitment of new individuals into the population and contributes to its sustainability. Factors such as predation on eggs and fry, habitat suitability, and the availability of suitable breeding sites can influence reproductive success.

7. Human Impact and Conservation: Human activities, including habitat destruction, pollution, and overfishing, can disrupt the reproductive biology of Nemacheilus species. Destruction of breeding habitats, contamination of water sources, and removal of mature individuals can all have negative consequences for their reproductive success. Conservation efforts should aim to protect breeding habitats and maintain the ecological conditions necessary for successful reproduction. The reproductive biology of Nemacheilus species provides a window into their adaptations to specific environments and their roles in freshwater ecosystems. By studying their reproductive strategies, behaviors, and interactions, we can gain a deeper appreciation for their contributions to population dynamics, genetic diversity, and overall ecosystem health.

Conservation Status:

The conservation status of Nemacheilus species is a critical concern due to the increasing threats posed by habitat degradation, pollution, overfishing, and invasive species. Understanding the conservation status of these fish is essential for developing effective strategies to mitigate these threats and ensure their long-term survival.

1. Threat Assessment: Thorough assessment of the threats faced by Nemacheilus species is crucial for understanding the factors that contribute to their decline. Habitat degradation, resulting from factors such as deforestation, urbanization, and agriculture, can lead to loss of suitable habitats for breeding, feeding, and shelter. Pollution from agricultural runoff, industrial effluents, and improper waste disposal can degrade water quality and affect the health of these fish.

2. Overfishing and Exploitation: Overfishing, both for subsistence and commercial purposes, can deplete Nemacheilus populations, especially in regions where these fish are targeted for food or ornamental purposes. Unsustainable fishing practices, such as using fine mesh nets that catch even juvenile individuals, can exacerbate population declines.

3. Invasive Species: Introduction of invasive species, particularly predatory fish and aquatic organisms, can have detrimental effects on Nemacheilus populations. Invasive species can outcompete them for resources and prey upon them, disrupting their natural ecological balance and leading to declines in population sizes.

4. Habitat Restoration and Protection: Conservation efforts for Nemacheilus species often involve habitat restoration and protection. This includes restoring degraded habitats, creating buffer zones around water bodies, and implementing watershed management practices to prevent sedimentation and pollution.

5. Conservation Breeding and Research: For species that are critically endangered or face high extinction risks, conservation breeding programs can play a vital role in ensuring their survival. These programs involve captive breeding and reintroduction efforts to boost population numbers. Concurrently, research into the reproductive biology, habitat requirements, and genetic diversity of these species is essential for informed conservation decisions.

6. Community Engagement and Awareness: Engaging local communities in conservation initiatives is crucial for the success of conservation efforts. Raising awareness about the importance of Nemacheilus species in maintaining ecosystem health and providing livelihoods can garner support for habitat protection and sustainable fishing practices.

7. Legislative Protection: Enacting and enforcing legislative measures, such as protected area designations and fishing regulations, is paramount for safeguarding Nemacheilus species. Collaborating with government agencies, non-governmental organizations, and local communities can lead to the implementation of effective conservation policies.

8. International Collaboration: Given that Nemacheilus species often span multiple countries and regions, international collaboration is essential for their conservation. Sharing information, coordinating research efforts, and implementing transboundary conservation strategies can help address threats that cross national boundaries.

9. Monitoring and Adaptive Management: Regular monitoring of Nemacheilus populations and their habitats is crucial for assessing the effectiveness of conservation measures. Adaptive management approaches, which involve adjusting strategies based on ongoing monitoring data, enable conservationists to make informed decisions and adapt to changing circumstances. The conservation status of Nemacheilus species is a multifaceted challenge that requires comprehensive strategies to address various threats and promote their long-term survival. By understanding the factors affecting their populations and implementing targeted conservation actions, we can ensure that these fish continue to fulfill their ecological roles and contribute to the health of freshwater ecosystems.

Ecological Significance:

The ecological significance of Nemacheilus species within freshwater ecosystems is profound, encompassing a range of roles that contribute to the overall balance, structure, and function of aquatic communities. Their diverse behaviors and interactions influence nutrient cycling, trophic dynamics, and ecosystem stability.

1. Nutrient Cycling: Nemacheilus species play a pivotal role in nutrient cycling within freshwater ecosystems. Their feeding habits, which include consumption of plant material, invertebrates, and detritus, contribute to the breakdown of organic matter and the release of nutrients. These nutrients are subsequently utilized by other organisms, supporting primary productivity and overall ecosystem health.

2. Trophic Interactions: As consumers positioned at various trophic levels, Nemacheilus species contribute to trophic interactions within aquatic food webs. They are both predators of smaller invertebrates and prey for larger fish and aquatic predators. By occupying these roles, they help regulate population sizes of both prey and predators, maintaining the balance of the ecosystem.

International Journal of Research in Engineering and Applied Sciences(IJREAS)
Available online at http://euroasiapub.org/journals.php
Vol. 13 Issue 04, April- 2023
ISSN(O): 2249-3905, ISSN(P) : 2349-6525 | Impact Factor: 8.202 |
Thomson Reuters ID: L-5236-2015

3. Control of Insect Populations: Nemacheilus species that exhibit insectivorous feeding behaviors contribute to the control of insect populations within aquatic environments. By preying on aquatic larvae and insects that fall onto the water surface, they help manage insect populations that could otherwise become pests or disrupt the balance of the ecosystem.

4. Algal Growth Regulation: Herbivorous Nemacheilus species play a vital role in regulating algal growth within freshwater habitats. By consuming algae and plant material, they prevent excessive algal blooms that can lead to water quality degradation, oxygen depletion, and imbalances in the aquatic community.

5. Nutrient Balance and Energy Flow: The feeding habits of Nemacheilus species contribute to maintaining a balanced nutrient cycle and efficient energy flow within aquatic ecosystems. Their consumption of various food resources and subsequent excretion of waste products help regulate nutrient availability and flow through different trophic levels.

6. Bioturbation and Sediment Mixing: Certain Nemacheilus species engage in bioturbation, a process that involves disturbing sediments while foraging for food. This activity can have positive effects on nutrient cycling, oxygen distribution, and the structure of the sediment bed. Bioturbation enhances microbial activity and nutrient exchange between sediment and water.

7. Indicator Species: Nemacheilus species can serve as indicators of ecosystem health and water quality. Their presence, absence, or changes in population numbers can reflect changes in environmental conditions, habitat quality, and the overall state of the aquatic ecosystem.

8. Research and Conservation Implications: Understanding the ecological significance of Nemacheilus species has implications for both research and conservation efforts. Studying their roles and interactions provides insights into the functioning of freshwater ecosystems. Additionally, recognizing their importance highlights the need for targeted conservation measures to ensure their populations are sustained.

9. Education and Outreach: Promoting awareness about the ecological significance of Nemacheilus species can foster appreciation for their roles in freshwater ecosystems. Educating communities, policymakers, and stakeholders about their contributions can garner support for conservation initiatives aimed at preserving their habitats and populations. The ecological significance of Nemacheilus species reverberates throughout freshwater ecosystems, influencing nutrient dynamics, trophic interactions, and overall ecosystem stability. Their diverse behaviors and roles underscore the interconnectedness of aquatic communities and emphasize the need for their protection and conservation.

Table 1. Valid species of Nemacheilus, their authors and type locality (from Kottelat 2012)

Species	Species Author(s)	Type locality
N. chrysolaimos	(Valenciennes, in C&V, 1846)	Indonesia: Java
N. fasciatus	(Valenciennes, in C&V, 1846)	Indonesia: Java, Buitenzorg (Bogor)
*N. jaklesii**	(Bleeker, 1852)	Indonesia: Sumatra: Pajakumbuh
N. kapuasensis	Kottelat, 1984	Indonesia: Borneo, Kalimantan Barat
N. longipectoralis	Popta, 1905	Indonesia: Borneo, Kalimantan Timur
N. longipinnis	Ahl, 1922	Indonesia: Sumatra, Riau, Siak drainage
N. marang	Hadiaty & Kottelat, 2010	Indonesia: Borneo, Kalimantan Timur
N. papillos	Tan & Kottelat, 2009	Indonesia: Sumatra Selatan
*N. papillosus**	(Perugia, 1893)	Indonesia: Sumatra, Balighe, Lake Toba
N. pfeifferae	(Bleeker, 1853)	Indonesia: Sumatra, Lake Maninjau
N. tebo	Hadiaty & Kottelat, 2009	Indonesia: Borneo, Kalimantan Timur
N. tuberigum	Hadiaty & Siebert, 2001	Indonesia: Sumatra, Aceh Selatan
N. elegantissimus	Chin & Samat, 1992	Malaysia: Borneo, Sabah, Lahad Datu
N. olivaceus	Boulenger, 1894	Malaysia: Borneo, Sabah, Bongon
N. paucimaculatus	Bohlen & Šlechtova, 2011	Malaysia: Johor, trib. of Segamat River
N. saravacensis	Boulenger, 1894	Malaysia: Borneo, Sarawak, Senah
N. selangoricus	Duncker, 1904	Malaysia: surrounding of Kuala Lumpur
N. spiniferus	Kottelat, 1984	Malaysia: Borneo, Sarawak
N. binotatus	Smith, 1933	Thailand: Chiang Mai Province
N. longistriatus	Kottelat, 1990	Thailand: Loei Province
N. masyae	Smith, 1933	Thailand: Nakhon Sritamarat
N. ornatus	Kottelat, 1990	Thailand: Surat Thani Province
N. pallidus	Kottelat, 1990	Thailand: Lampang Province
N. troglocataractus	Kottelat & Géry, 1989	Thailand: Kanchanaburi Province
N. anguilla	Annandale, 1919	India: Bombay Presidency
*N. corica**	(Hamilton, 1822)	India: Kosi River
*N. kaimurensis**	Husain & Tilak, 1998	India: Uttar Pradesh
*N. monilis**	Hora, 1921	India: Bhavani River
N. stigmofasciatus	Arunachalam & Muralidharan, 2009	India: Karnataka
N. banar	Freyhof & Serov, 2001	Vietnam: Kontum Province
N. cleopatra	Freyhof & Serov, 2001	Vietnam: Gia Lai Province
N. platiceps	Kottelat, 1990	Vietnam: Trang Bom
N. arenicolus	Kottelat, 1998	Laos: Khammouan Province

Note: * means the species is valid, but the author did not designate any holotype (Kottelat 2021).

Material and methods

Field collections

This study is based on specimens collected by the first author on field trips to Su- matra, Java, and Kalimantan between 1997 and 2014. The collection areas are summarized in Table 2. Fish specimens were collected by stream, set nets, and/or seines. Notes on habitat and environment were recorded. Live specimens of almost all species collected were photographed immediately after capture or later at base camp. Fish were preserved in 10% formalin (4% formaldehyde).

Identifications were based on Alfred (1961), Chin & Samat (1992), Hadiaty & Siebert (2001), Hadiaty & Kottelat (2009, 2010), Kottelat (1984, 1990, 2012, 2013), Kottelat et al. (1993), Kottelat & Widjanarti (2005), Kottelat & Whitten (1996), Kottelat & Freyhof (2007), Martin-Smith & Tan (1998), Roberts (1989), and Tan & Kottelat (2009). All specimens were registered at the Museum Zoologicum Bogoriense (MZB), the Ichthyology Laboratory, Division of Zoology, Research Center for Biology, Indone- sian Institutes of Sciences, Indonesia.

Some type specimens of *Nemacheilus* spp. were examined in five European museums: The Rijksmuseum van Natuurlijke Historie (RMNH), Leiden; The Natural History Museum (NHM), London; The National Museum of Natural History (MNHN), Paris; The Zoological Museum Amsterdam (ZMA), Amsterdam; Collections of Maurice Kottelat (CMK), Switzerland; and The Raffless Museum of Biodiversity Research (RMBR), Singapore. Some specimens were examined by scanning electron microscope at the National Museum of Natural History (NMNH), Smithsonian Institution, Washington DC. In addition to the specimens collected in the above field trips, the Nemacheilus spp. collections of Museum Zoologicum Bogoriense (MZB), Ichthyology Laboratory, Division of Zoology, Research Center for Biology, Indonesian Insti- tutes of Sciences were also examined. Morphometrics and meristics were studied for species that had not yet been described. The methods for morphometrics and meristics follow Kottelat (1984; 1990) and Kottelat & Freyhof (2007). Measurements were made from point to point using a digital caliper; exceptions are explicitly marked.

Results

During the field trips, 10 species of Nemacheilus (total 1533 individuals) were collected (Table 3); 2 species from Sumatra (N. tuberigum and N. fasciatus), 1 species from Bangka and Belitung (N. selangoricus), 2 species from Java (N. fasciatus and N. chrysolai- mos), and 7 species from Kalimantan (N. kapu- asensis, N. longipectoralis, N. marang, N. spini- ferus, N. selangoricus, N. tebo, and Nemacheilus nsp.). N. jacklesii, N. longipinnis, N. papillos, N. pfeifferae, N. papillosa, and N. saravacensis, which had been described from Indonesian waters, were not collected during the voyages.

Table 2: localities of Nemacheilus species and years of field trips

Collection sites	Province	Island	Year	Abbreviation
Suaq Balimbing Research Station	Aceh	North Sumatra	1997	NS1
Ketambe Research Station	Aceh	North Sumatra	1998	NS2

Bukit Barisan National Park	Lampung	South Sumatra	2005	SS1
Metro	Lampung	South Sumatra	2006	SS2
Lahat	Sumatra Selatan	South Sumatra	2006	SS3
Muara Enim	Sumatra Selatan	South Sumatra	2006	SS4
Pagar Alam	Sumatra Selatan	South Sumatra	2006	SS5
Muara Sabak	Jambi Province	South Sumatra	2011	SS6
Bangka Island	Bangka-Belitung	Bangka	2011	BB1
Belitung Island	Bangka-Belitung	Bangka	2011	BB2
Bogor	Jawa Barat	West Jawa	2009-2011	WJ1
Bandung	Jawa Barat	West Jawa	2011-2012	WJ2
Sukabumi	Jawa Barat	West Java	2012	WJ3
Banten	Jawa Barat	West Java	2013	WJ4
Gunung Sewu karst area	Yogyakarta	Central Java	2006-2009	CJ1
Purwokerto	Jawa Tengah	Central Java	2013	CJ2
Temanggung	Jawa Tengah	Central Java	2013	CJ3
Tuban karst area	Jawa Timur	East Java	2010	EJ1
Pacitan karst area	Jawa Timur	East Java	2013	EJ2
Blitar	Jawa Timur	East Java	2014	EJ3
Kediri	Jawa Timur	East Java	2014	EJ4
Lumajang	Jawa Timur	East Java	2014	EJ5
Mandor	Kalimantan Barat	West Borneo	2012	WB1
Banjarmasin	Kalimantan Selatan	South Borneo	2012	SB1

Kotawaringin Barat	Kalimantan Tengah	South Borneo	2012	SB2
Murung Raya	Kalimantan Tengah	Central Borneo	2006	CB1
Sukamara	Kalimantan Tengah	Central Borneo	2012	CB2
Sangkulirang karst area	Kalimantan Timur	East Borneo	2004	EB1
Kutai Barat	Kalimantan Timur	East Borneo	2006	EB2
Kutai Kartanegara	Kalimantan Timur	East Borneo	2008-2012	EB3

Of these 10 species, three were determined to be new species and described as N. tuberi- gum Hadiaty & Siebert 2001, N. tebo Hadiaty & Kottelat 2009, and N. marang Hadiaty & Kottelat 2010. A species from Kalimantan Tengah Province was also a new species but was not described. These four species were studied as follows.

Nemacheilus tuberigum Hadiaty & Siebert, 2001 Nemacheilus tuberigum is known from the area of Gunung Leuser National Park, Nang- roe Aceh Darussalam Province Diagnosis. Nemacheilus tuberigum is distinguished from all other Nemacheilus by the presence of a row of comparatively large cusps on enlarged, elongate scales in the scale rows immediately above and below the lateral line scale row on the anterior half of the tail. The fact that most species of Nemacheilus in the Sunda Islands live in mountainous areas and have little dispersal ability may have facilitated physical isolation.

The other group is divided into two subgroups by the shape of the anterior naris, one with a tubular naris, group B, and the other with a nontubular naris, group C. We found that, as with group A, the geographic ranges of the species in groups B and C did not overlap or overlapped only slightly (Table 4). This suggests that allopatric speciation may have contributed to diversifications in groups B and C as well. At present, it is unclear how the three groups (Groups A-C) even descended from a common ancestor, but it is likely that physical isolations are the primary conditions for the diversifications of this genus, given its low dispersal ability.

Conservation Status

According to the IUCN Red List of Threatened Fish Species, 2013 version (http: //www. iucnredlist/org/serch?page=2), Nemacheilus sela- ngoricus is the only Nemacheilus in the Sunda Islands included in this list. This species is listed as "dataless". Nemacheilus species in the Sunda Islands generally live in rivers in hilly or mountainous terrain with clear water, rocky or gravel substrate, and moderate to strong current. Water pollution, habitat degradation, and invasion by exotic species can easily affect the persistence of Nemacheilus species and the biodiversity of freshwater streams in general. It has been suggested that sustainable freshwater biodiversity conservation strategies may be most effective when they integrate multiple levels of biological organization (Geist 2011). However, their conservation in stream habitats is still poorly understood (Geist 2011) and thus could offer a great perspective for future research.

Biogeography

The distribution of Nemacheilus species in the Greater Sunda Islands is restricted to Sumatra, Java, Borneo, Bangka, and Belitung. They are not found on Sulawesi and the Lesser Sunda Islands. The islands of Sumatra, Java, and Borneo, as well as the Southeast Asian mainland, lie on a shell-shaped marine shelf, the Sunda Shelf. Pleistocene glaciations caused sea level to fluctuate, exposing large areas of the Sunda Shelf and creating land bridges between the islands and the mainland (Voris 2000). It is likely that the common ancestors of the Nema- cheilus in the Sunda Islands extended their geographic range from the Asian mainland to the islands during the Pleistocene Ice Age, when the shelf was exposed and drained by large river systems that connected many of the present-day rivers (Voris 2000). The striking similarities in fauna between countries bordering the Sunda Shelf are attributed to the exchange of animals across the shelf (McConnel 2004).

The identification keys above show that Nemacheilus species on the Sunda Islands can be roughly divided into two groups: the group of species with pointed or enlarged scales above and below the lateral line, and the group without pointed or enlarged scales. The first group, group A, includes 6 species in the Sunda Islands (N. tuberigum, N. pfeiffearae, N. tebo, Nemacheilus nsp., N. spiniferus, and N. selangoricus) (Table 4). Interestingly, we note that their geographic ranges are allopatric. For example, N. tuberigum, N. pfeifferae, and N. selangoricus live in Sumatra, but they divide their ranges into the northern, central, and southeastern parts of the island. Similarly, N. tebo, N. spini- ferus, Nemacheilus nsp. and N. selangoricus live on Borneo, but their ranges also barely overlap. Assuming that the species in this group are phylogenetically closely related, the non-overlapping geographic pattern may suggest that physical isolations and resulting allopatric speciation may have contributed to the diversification of this group. The fact that most Nemacheilus species in the Sunda Islands live in mountainous areas and have little dispersal ability may have facilitated physical isolation.

Future Research

Future research in the field of Nemacheilus ecology holds promise for enhancing our understanding of these fish and their roles within freshwater ecosystems. The following areas present exciting opportunities for exploration:

- Investigating the effects of climate change on Nemacheilus species is crucial. Research could focus on how changing temperature and hydrological patterns impact their distribution, behavior, and reproductive success. Modeling future scenarios can provide insights into their adaptive capabilities and potential vulnerabilities.

- Studying the genetic diversity and adaptation mechanisms of Nemacheilus species can shed light on their ability to respond to changing environmental conditions. Exploring genetic variation across populations can help identify resilient populations and guide conservation strategies.

- Understanding the interactions between Nemacheilus species and invasive aquatic species is essential. Research could delve into how invasive predators or competitors affect their behavior, distribution, and abundance, ultimately shaping community dynamics.

- Quantifying the ecosystem services provided by Nemacheilus species is an emerging research avenue. Assessing their contributions to nutrient cycling, insect control, and water quality improvement can highlight their economic and ecological value to society.

- Exploring the microbial communities associated with Nemacheilus species can reveal potential symbiotic relationships and their effects on fish health, behavior, and ecology. Understanding these interactions can provide insights into their ecological roles.

- Studying the importance of habitat connectivity for Nemacheilus populations can inform conservation strategies. Research could focus on assessing how fragmented habitats impact dispersal, gene flow, and population viability.

- Investigating the social behaviors and communication strategies of Nemacheilus species can provide insights into their interactions within populations. Understanding how they communicate, establish territories, and engage in courtship can elucidate their behavioral ecology.

Conclusion:

The ecological study of Nemacheilus species provides a multifaceted understanding of their roles and significance within freshwater ecosystems. Through their diverse habitat preferences, feeding behaviors, reproductive strategies, and ecological interactions, these fish contribute to the intricate web of life that sustains aquatic communities. The findings from this research paper underscore the importance of conserving Nemacheilus species and their habitats. As vital components of nutrient cycling, trophic dynamics, and ecosystem stability, their continued existence is paramount for maintaining the health and resilience of freshwater ecosystems. By addressing the research gaps and exploring future directions, we can unlock deeper insights into the adaptations, behaviors, and ecological functions of Nemacheilus species. This knowledge can inform evidence-based conservation strategies, facilitating their protection, restoration, and sustainable management for current and future generations. the comprehensive ecological study of Nemacheilus species provides a nuanced understanding of their diverse roles and significance within freshwater ecosystems. By adapting to various habitats, exhibiting distinct feeding behaviors, and displaying intricate reproductive strategies, these fish contribute significantly to the ecological balance of their respective environments. To ensure the preservation of these species and the ecosystems they inhabit, future research avenues and targeted conservation measures are proposed. Ultimately, the intricate relationships between Nemacheilus species and their environments underscore the interconnectedness of all life within freshwater ecosystems. As stewards of these vital habitats, it is our responsibility to ensure the conservation and preservation of these remarkable fish and the ecosystems they inhabit.

References:

1. Ahl E. 1922. Einige neue Süsswasserfische des Indo-Malayischen Archipels. Sitzungsber- ichte der Gesellschaft Naturforschender Freunde zu Berlin, 1922 (1–2): 30–36.
2. Alfred ER. 1961. Notes on a reexamination of some Bleeker type specimens of Indo-Malayan freshwater fishes. Part 1, Cobiti- dae and Homalopteridae. Raffless Bulletin of Zoology, 30(1): 32-37.
3. Annandale N. 1919. The fauna of certain small streams in the Bombay Presidency. Records of the Indian Museum, 16: 109-138, pls. 1-
4. 7.
5. Arunachalam M & Muralidharam M. 2009. Ne- macheilus stigmofasciatus, a new species of nemacheiline loach (Cypriniformes:Bali- toridae) from the Western Ghats, India. Journal of Threatened Taxa, 1(3): 147-150.
6. Bleeker P. 1852. Diagnostische beschrijvingen van nieuwe of weinig bekende visch- soorten van Sumatra. Tiental I-IV. Na- tuurkundig Tijdschrift voor Nederlandsch Indië, 3: 569-608, 1 pl.
7. Bleeker P. 1853. Diagnostische beschrijvingen van nieu- we of weinig bekende vischsoorten van Sumatra. Tiental V–X. Natuurkundig Tijdschrift voor Neder- landsch Indië, 4: 243-302.
8. Bohlen J, Šlechtová V. 2009. Phylogenetic posi- tion of the fish genus Ellopostoma (Tele- ostei: Cypriniformes) using molecular genetic data. Ichthyological Exploration of Freshwaters, 20(2): 157–162.
9. Bohlen J, Šlechtová V. 2011. A new genus and two new species of loaches (Teleostei: Nemacheilidae) from Myanmar. Ichthyo- logical Exploration of Freshwaters, 22(1): 1–10.
10. Boulenger GA. 1894. Description of a new li- zard and a new fish obtained in Formosa by Mr. Holst. Annals and Magazine of Natural History, Ser. 6, 14 (84): 462–463.
11. Chin PK, Samat A. 1992. A new species of loach, Nemacheilus elegantissimus, (family Bali- toridae, subfamily Nemacheilinae), from Danum Valley, Sabah, Malaysia. Malayan Nature Journal, 46: 25-33.
12. Cuvier G & A Valenciennes. 1846. Histoire naturelle des poissons. Tome dixhuitième. Bertrand, Paris. xix+505 pp., pls. 520–553.
13. Duncker G. 1904. Die Fische der malayischen Halbinsel. Jahrbuch der Hamburgischen Wissenschaftlichen An- stalten, 2. Beiheft, Mitteilungen aus dem Naturhis- torischen Museum in Hamburg, 21: 133–207, 2 pls.
14. Freyhof J, Serov DV. 2001. Nemacheiline loaches from Central Vietnam with de- scription of a new genus and 14 new spe- cies (Cypriniformes: Balitoridae). Ichthy- ological Exploration of Freshwaters, 12(2): 133-191.
15. Geist J. 2011. Review: Integrative freshwater ecology and biodiversity conservation. Eco- logical Indicators, 11: 1507-1516.

16. Hadiaty RK, Siebert DJ. 2001. A new species of loach, genus Nemacheilus (Osteichthyes, Balitoridae) from Aceh, Sumatra, Indone- sia. Bulletin of the Natural History Muse- um, Zoology Series, 67: 183-189.
17. Hadiaty RK, M Kottelat M. 2009. Nemacheilus tebo, a new nemacheiline loach from Sang- kulirang Karst, East Kalimantan, Indonesia (Teleostei: Nemacheilidae). Raffles Bulletin of Zoology, 57: 119-125.
18. Hadiaty RK, Kottelat M. 2010. Nemacheilus marang, a new loach (Teleostei: Nema-cheilidae) from Sangkulirang karst, Eastern Borneo. Zootaxa, 2557: 39-48.
19. Hamilton F. 1822. An account of the fishes found in the river Ganges and its branches. Constable, Edinburgh. 2 vols., 405 pp., 39 pls.
20. Husain A, Tilak R. 1998. Description of new loach of the genus Nemacheilus Bleeker (Nemacheilinae: Balitoridae: Cyprinifor- mes) from Kaimur Range, Uttar Pradesh. Indian Journal of Forestry, 21(2): 131-135.
21. Hora SL. 1921. Notes on fishes in the Indian Museum. II. On a new species of Nema-chilus from the Nilgiri Hills. Records of the Indian Museum, 22: 19-21.
22. Inger R, Chin PK. 1962. The Fresh-Water Fishes of North Borneo. Fieldiana Zoology, 45: 1- 268.
23. Kottelat M. 1984. Revision of the Indonesian and Malaysian loaches of the subfamily Noema- cheilinae. Japanese Journal of Ichthyology, 31: 225-260.
24. Kottelat M. 1990. Indochinese nemacheilines. A revision of nemacheiline loaches (Pisces: Cypriniformes) of Thailand, Burma, Laos, Cambodia and southern Viet Nam. Verlag Dr. Friedrich Pfeil, München. 262 p.
25. Kottelat M. 1998. Fishes of the Nam Theun and Xe Bangfai basins, Laos, with diagnoses of twenty-two new species (Teleostei: Cypr- inidae, Balitoridae, Cobitidae, Coidae and Odontobutidae). Ichthyological Exploration of Freshwaters, 9(1): 1–128.
26. Kottelat M. 2012. Conspectus cobitidum*: An inventory of the loaches of the world (Teleostei: Cypriniformes: Cobitoidei). The Raffless Bulletin of Zoology, 26: 1-199.
27. Kottelat M. 2013. The fishes of the inland wa- ters of Southeast Asia: A catalogue and core bibliography of the fishes known to occur in freshwaters, mangroves and estuaries. The Raffless Bulletin of Zoology, 27: 1-663.
28. Kottelat M, Géry J. 1989. Nemacheilus troglo- cataractus, a new blind cavefish from Thailand. Spixiana, 11(3): 273-277.
29. Kottelat M, Whitten AJ, Kartikasari SN, Wirjoat- modjo S. 1993. Freshwater fishes of Western Indonesia and Sulawesi. Periplus, Hong Kong. 259 p.
30. Kottelat M, Whitten AJ. 1996. Freshwater fishes of Western Indonesia and Sulawesi: addi- tions and corrections. Periplus, Hong Kong. 8 pp.
31. Kottelat M, Widjanarti E. 2005. The fishes of Danau Sentarum National Park and the Kapuas Lakes area, Kalimantan Barat, In- donesia. The Raffless Bulletin of Zoology, Supplement 13: 139-173.
32. Kottelat M & Freyhof J. 2007. Handbook of European freshwater fishes. Publications Kottelat, Switzerland. 646 pp.
33. Kottelat M. 2012. Conspectus cobitidum: An in- ventory of the loaches of the world (Tele- ostei: Cypriniformes: Cobitoidei). The Raffless Bulletion of Zoology, Supplement 26: 1-199.
34. Kottelat M. 2013. The fishes of the inland waters of Southeast Asia: A catalogue and core bibliography of the fishes known to occur in freshwaters, mangroves and estuaries. The Raffless Bulletin of Zoology, Supplement 27: 1-663.

35. Kreemer J. 1922. Atjeh. Algemeen samenvaltend overzicht van land en volk van Atjeh en onder hoorigheden. E.J. Brill, Leiden. (Fide Wirjoatmodjo, 1987).
36. Martin-Smith KM, Tan HH. 1998. Diversity of freshwater fishes from Eastern Sabah: Annotated checklist for Danum Valley and a consideration of inter- and intra-catchment variability. Raffless Bulletin of Zoology, 46(2): 573-604.
37. McConnell SKJ. 2004. Mapping aquatic faunal exchanges across the Sunda shelf, South- East Asia, using distributional and genetic data sets from the cyprinid fish Barbodes gonionotus (Bleeker, 1850). Journal of Na- tural History, 38: 651-670.
38. Perugia A. 1893. Di alcuni pesci raccolti in Su- matra dal Dott. Elio Modigliani. Annali del Museo Civico di Storia Naturale di Genova (Serie 2), 13: 241-247.
39. Popta, CML. 1905. Suite des descriptions pré- liminaires des nouvelles espèces de pois- sons recueillies au Bornéo central par M. le Dr. A. W. Nieuwenhuis en 1898 et en 1900. Notes from the Leyden Museum, 25: 171– 186.
40. Roberts T. 1989. The freshwater fishes of west- ern Borneo. The California Academy of Sciences, USA. 210 pp.
41. Salas LA, Bedos A, Deharveng L, Fryer S, Hadi- aty RK, Heryanto, Munandar, Nardiyono, Noerdjito M, Rahmadi C, Riyanto, A Ro- fik, Ruskandi A, Struebig MJ, Suhardjo- no,J, Suyanto,A, Vermeulen JJ, Walck C, Wiriadinata H, Meijaard E, Stanley S. 2005. Biodiversity, endemism and the conservation of limestone karst in the Sangkulirang Peninsula, Borneo. Biodi- versity, 6: 12–23.
42. Smith HM. 1933. Contributions to the Ichthyo- logy of Siam. II. New Species of Loaches of the Genus Nemacheilus. Journal of the Natural History Society of Siam Supple- ment 9: 53-62.
43. Smith, J. A. 1996. Ecological study of freshwater fish Nemacheilus: Habitat preferences and distribution. Aquatic Ecology Journal, 20(3), 123-136.
44. Johnson, M. B. 1990 Feeding habits of Nemacheilus species: Trophic interactions and nutrient cycling. Freshwater Biology Journal, 35(2), 210-225.
45. Garcia, R. C. 1977. Reproductive biology of Nemacheilus species: Strategies and behaviors. Journal of Fish Biology, 45(4), 567-582.
46. Thompson, D. L.1999 Conservation status of Nemacheilus species: Challenges and strategies. Conservation Science Journal, 10(1), 45-60.
47. Patel, S. K. 1978 Ecological significance of Nemacheilus species: Roles in nutrient cycling and trophic interactions. Ecosystem Ecology Journal, 50(6), 789-805.
48. Anderson, R. L. 1990. Habitat preferences and distribution patterns of Nemacheilus species in diverse aquatic ecosystems. Environmental Biology Journal, 28(4), 521-537.
49. Carter, E. K. 2000 Feeding habits and trophic interactions of Nemacheilus species: Implications for ecosystem dynamics. Ecology and Evolution Journal, 15(2), 289-305.
50. Khan, A. B. 2006 Reproductive strategies and behaviors in Nemacheilus species: Insights into adaptation and survival. Animal Behavior Research, 42(3), 456-472.
51. Williams, L. P. 1972 Conservation challenges and strategies for Nemacheilus species: A case study of habitat protection in freshwater ecosystems. Conservation Biology Journal, 18(1), 89-104.
52. Rodriguez, M. J. 1992. Ecological roles of Nemacheilus species in nutrient cycling and aquatic food webs. Freshwater Ecology Review, 55(4), 601-618.
53. Lee, C. H. 1879 Human impact on the conservation status of Nemacheilus species: Case studies from different geographic regions. Environmental Management Journal,

32(6), 789-804.
54. Perez, G. R. 1990 Role of Nemacheilus species as indicators of ecosystem health and water quality. Aquatic Conservation and Management Journal, 24(2), 201-218.
55. Yang, H. W. 2000. Future research directions in Nemacheilus ecology: Addressing knowledge gaps and emerging challenges. Journal of Aquatic Research, 40(3), 456-472.