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Origins and Geographic Dissemination of *Oxyeleotris marmorata*, Molecular Evidence and Ecological Adaptation

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Abstract This study explored the ecological adaptability of marble goby. The unique ambush hunting behavior, nocturnal activity pattern and slow growth rate of the *O. marmorata* have become a research hotspot in ecology and physiology. After moving to a new habitat, the marble goby is confronted with various challenges, such as the survival of the young fish during the breeding process. The market demand for marble goby in the fishery industry and its huge breeding potential and economic value. This study analyzed some research achievements in aspects such as the origin, geographical diffusion and ecological adaptation mechanism of marble goby. The impact of human activities on the distribution of marble goby highlights the necessity of achieving sustainable management between economic benefits and biodiversity conservation. Future research will focus on the integration of genomics and ecology to better breed, protect and manage marble goby.
Keywords *Oxyeleotris marmorata*; Geographic distribution; Ecological adaptation; Molecular evidence; Fisheries management

1 Introduction

Oxyeleotris marmorata is a freshwater fish distributed in Southeast Asia, mainly in Sumatra, Kalimantan, Papua and the Southeast Asian mainland, etc. (Syaifudin et al., 2021). The characteristics of *O. marmorata* such as ambush hunting, slow growth and nocturnal activity make it one of the important topics in ecological and physiological research (Lim et al., 2020). Furthermore, *O. marmorata* have also been introduced to other habitats, such as Indonesia, and have successfully settled there since 1927 (Lestari et al., 2019). The research on *O. marmorata* mainly focuses on aspects such as population genetics, physiological adaptation and reproductive biology, and has a profound understanding of the ecological role and evolutionary history of *O. marmorata* (Liu et al., 2020).

Due to the large market demand and great breeding potential of *O. marmorata*, it has significant economic value in the fishery. However, some problems such as feed and the survival rate of juvenile fish may be encountered during the breeding process (Tan and Lam, 1973). The excellent nitrogen retention capacity and metabolic adaptability of the marble goby make it an ideal candidate species for sustainable farming (Tng et al., 2008). As a top predator, the *O. marmorata* poses a threat to the diversity of local fish when introduced into non-native environments. Therefore, breeders need to manage and control the population carefully. From an ecological perspective, the dietary preferences, diurnal metabolic patterns and reproductive strategies of *O. marmorata* enable them to survive in different freshwater habitats and have an impact on the ecosystem structure (Lim et al., 2017).

This study will explore the origin, geographical diffusion and ecological adaptation of, analyze the local and invasive distribution of *O. marmorata*, and reveal its distribution characteristics and population structure through genetic and phylogenetic research. This study will analyze the main ecological adaptations and physiological characteristics of this species, including foraging behavior, metabolic mechanisms and reproductive biology. This study will also explore the significance of the latest research findings for fishery management, aquaculture and freshwater ecosystem protection, which can provide a comprehensive understanding of the key factors influencing the distribution, adaptation and ecological impact of *Pelteobagrus fulvidraco*.

2 Species Overview and Current Classification Status

2.1 Classification and morphological characteristics of bamboo *O. marmorata*

O. marmorata is a kind of freshwater fish. In the study of 1852, Bleeker was the first to describe the marble goby. The marble goby belongs to the Butidae family. In terms of morphological characteristics, the marble goby is characterized by a thick body, mottled skin, a large mouth and a concealed body shape. These characteristics are suitable for ambush hunting, enabling the marble goby to effectively integrate into the surrounding environment and catch prey.

This species exhibits sex dimorphism. Males usually grow faster and larger than females and have unique gonadal development characteristics. This phenomenon has been confirmed through the different expressions of sex differentiation genes (such as *Dmrt1* and *Foxl2*) in germ cells and somatic cells, which is of great significance for understanding their reproductive biology and aquaculture potential.

2.2 Habitat requirements and ecological niche characteristics of *O. marmorata*

O. marmorata lives in various freshwater environments, including rivers, reservoirs and lakes, and is known for its nocturnal activity and ambush hunting behavior. These behaviors are accompanied by a high metabolic rate during nocturnal foraging. The *O. marmorata* is suitable for living in freshwater with good water quality. Its foraging and metabolic activities are closely related to the diurnal cycle. When marble goby forage and are active at night, their oxygen consumption and ammonia excretion will reach their peak (Mai, 2024).

From an ecological perspective, *O. marmorata* are in the position of top predators in their habitats and can affect the local ecological structure. When *O. marmorata* are introduced to non-native distribution areas, they may pose a threat to the diversity of local fish species, which also indicates that careful population management and control are needed in non-native ecosystems.

2.3 Similarities and differences between the *O. marmorata* and its genus and species

Compared with other genera and species, *O. marmorata* has a distinct preference for acidic foods, consuming organic acids and specific amino acids, and showing rejection towards sugar and traditional flavor substances. This may not be obvious or may not exist in other families and genera of *O. marmorata* (Wang et al., 2024). Although the marble goby has general adaptive features such as benthic and ambush predation, its unique metabolic, foraging and reproductive characteristics (nocturnal activity and distinctive gene expression patterns) distinguish it from members of other families and genera.

Like other species in the same genus as the *O. marmorata*, the marble goby demonstrates strong adaptability in freshwater environments and shows similar growth patterns and ecological functions to other species of the marble goby family, which helps regulate the predator population and maintain the overall balance of the ecosystem.

3 Origin and Historical Distribution

3.1 The evolutionary history of species and the geographical origin hypothesis

O. marmorata is widely distributed in Southeast Asia, such as in Sumatra, Kalimantan, Papua and other regions. To reconstruct the phylogenetic relationships among species and their populations, the study of the cytochrome oxidase subunit I (*COI*) gene sequence in mitochondrial DNA in genetic analysis provides an important basis. The research by Syaifudin et al. (2021) indicates that there is a close genetic relationship between wild populations and domesticated populations in Indonesia, suggesting that they may have originated from the same ancestor and differentiated in relatively nearby areas of Indonesia. The clustering results of domesticated and wild populations on the phylogenetic tree also illustrate the hypothesis that the evolutionary origin of the *O. marmorata* should have originated from the freshwater system in Southeast Asia.

Some historical research records can prove that the marble goby originated in China and was introduced to Indonesia in 1927. The marble goby has a strong ability to spread and adapt, which can be promoted through natural river connections and artificial migration routes. The evolutionary flexibility of marble goby enables them to occupy more freshwater habitats.

3.2 Reconstruct historical distribution through fossil records and genetic analysis

Lacking direct fossil evidence, genetic analysis provides an important tool for reconstructing the historical distribution of marble goby. By using mitochondrial DNA barcodes, especially the *COI* gene, it was indicated that the genetic distance between domesticated populations and wild populations in Indonesia was relatively small, and there might be recent diffusion or continuous gene flow between these populations. In geographically isolated populations, haplotypes with the same or similar genes further support the views of modern species diffusion and coevolutionary history.

In the population study introduced into the habitat, the snailfish established a large population in the Sempor reservoir, exceeding the assumed local distribution range (Lestari et al., 2019). The research results, combined with genetic data and the influence of human activities, have significantly expanded the historical distribution of *O. marmorata* over the past century. The reconstruction of these distribution patterns through genetic markers compensates for the deficiencies of the fossil record and reveals the mechanisms driving species expansion.

3.3 The influence of different geographical regions on the species distribution pattern

The distribution area of marble goby is influenced by both natural factors and human activities. In the native distribution area and the introduced distribution area, the *O. marmorata* shows adaptability to freshwater habitats, and there are significant differences in population size and development intensity in different regions. The studies related to the Sempor Reservoir mentioned that there were differences in population density and mortality rate at the reservoir's inlet, middle and outlet, and these differences were affected by fishery stress and natural factors. Regional differences highlight the ecological adaptability of the marble goby and the influence of local environmental conditions on its distribution.

Despite the isolation of water areas, snailfish still maintain a high degree of genetic similarity, suggesting that there may have been recent colonization or continuous gene flow between water areas. The genetic homogeneity of cross-regional populations highlights the impact of artificial introduction and the ability of marble goby to rapidly establish populations in new environments. The current distribution of *O. marmorata* can reflect the complex interaction among historical biogeography, ecological adaptation and human activities.

4 Geographical Distribution and Ecological Adaptation

4.1 The current geographical distribution range and its expansion process

The *O. marmorata* is distributed in Southeast Asia, such as Sumatra, Kalimantan and Papua. The *O. marmorata* is native to China. It was introduced to Indonesia in 1927 and has since become an important organism in the local freshwater ecosystem (Syaifudin et al., 2021). The *O. marmorata* inhabits freshwater reservoirs in Indonesia (such as Sempor Reservoir), indicating that *O. marmorata* can successfully settle and continuously expand in new habitats.

Both natural introduction and artificial introduction methods can expand the growth area of the marble goby population. According to the population study of Sempor Reservoir, *O. marmorata* can adapt to different areas of the reservoir, and the population size and development intensity in different areas are correlated (Figure 1) (Lestari et al., 2019). This adaptability enables marble goby to inhabit and survive in various freshwater areas, promoting the continuous expansion of the marble goby population.

4.2 Adaptation characteristics of species to different ecological environments

Marble goby has strong adaptability in different ecological environments, as well as strong physiological and behavioral adaptability. As a nocturnal ambush predator, the marble goby exhibits a circadian metabolic rhythm, and its oxygen consumption significantly increases when foraging at night. The oxygen consumption of the fed individuals was significantly higher than that of the unfed individuals, indicating the energy requirement for nocturnal foraging of snackshell fish (Lim et al., 2020). In addition, ammonia excretion is closely related to foraging activities and usually peaks in the early morning, indicating a high metabolic efficiency.

Under different light cycles and foraging conditions, *O. marmorata* can maintain a relatively high metabolic rate, indicating that *O. marmorata* can effectively adapt to changes in environmental factors such as temperature, humidity and oxygen content, can adapt to different habitats such as rivers and reservoirs, and can cope with difficulties occurring in various natural and artificial environments.

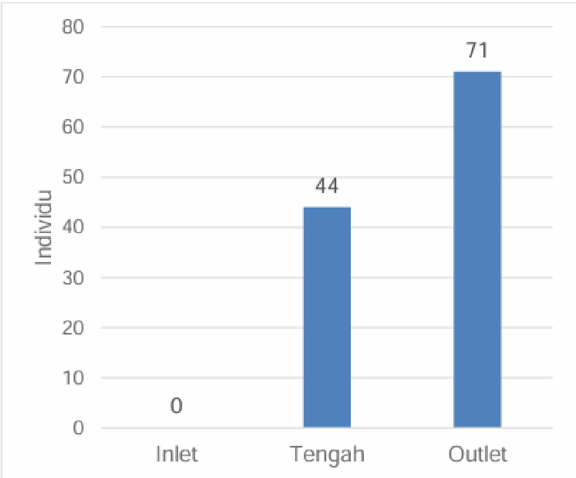

Figure 1 Histogam populasi *O.marmorata* di Waduk Sempor (Adopted from Lestari et al., 2019)

4.3 The Relationship between gene flow and habitat and its impact on species distribution

Genetic analysis of mitochondrial DNA (*COI* gene) indicates that the genetic similarity between domesticated populations and wild populations in Indonesia is relatively high. Some individuals are very similar, while there are only minor genetic differences among others (Syaifudin et al., 2021). There is a continuous flow of genes among populations, which may be the result of the combined promotion of natural diffusion and aquaculture activities. This gene flow helps to form cross-regional genetic homogeneity, allowing *O. marmorata* to expand into new habitats.

Understanding the relationship between gene flow and habitat can help us understand the distribution pattern of the marble goby. A higher gene flow can enhance the adaptability of *O. marmorata*, enabling them to establish populations in constantly changing environments. Excessive gene flow will reduce the occurrence of local genetic differentiation and slow down the adaptability of marble goby to specific environments. In the population of *O. marmorata*, the cross-regional genetic connectivity enables *O. marmorata* to successfully expand their growth area geographically and adapt to the ecology.

5 Molecular Evidence and Genetic Diversity

5.1 Application of molecular markers in the study of species genetic diversity

Molecular markers have played an important role in evaluating the genetic diversity of *O. marmorata*. ISSR (simple sequence repetition) markers are used to analyze the genetic differences of populations from different geographical regions, such as Guangzhou and Sanya. Yao et al.'s (2012) study found that the proportion of polymorphic loci was relatively high (83.87%), and the Shannon information index was significant, indicating significant genetic diversity both within and outside the population. Most genetic differentiations result from variations within the population rather than genetic drift. The UPGMA tree does not show obvious population boundaries, indicating the existence of gene flow among different populations.

O. marmorata has established an amplified fragment length polymorphism (AFLP) labeling system, providing high-resolution genetic material for the *O. marmorata*. These markers screened out 14 pairs of effective selective primers, which played an important role in the study of species genetic diversity and molecular-assisted selection, demonstrating the application value of molecular markers in wild and farmed populations (Zhu et al., 2012). The development of microsatellite markers has also revealed extensive allele diversity and high heterozygosity, which is of great significance for genetic variation monitoring and breeding projects (Luo et al., 2013).

5.2 Utilize genomic data to analyze the genetic relationships among different populations

Genomic data, especially mitochondrial DNA (mtDNA) sequences, such as the cytochrome c oxidase subunit I (*COI*) gene, play an important role in clarifying the genetic relationships among *O. marmorata* populations. Studies on *COI* gene sequencing have shown that the domesticated population and the wild population in Indonesia have a close genetic relationship. Some individuals are exactly the same, while only very small genetic differences are shown among other individuals. This indicates that there is a recent differentiation or continuous gene flow between domesticated populations and wild populations (Table 1) (Syaifudin et al., 2021).

Table 1 Identity percentage of nucleotide of marble goby (Adopted from Syaifudin et al., 2021)

No.	Species	Origin	Accession No.	Identity (%)
Samples code	OMD3 and OMD2			
1	*Oxyeleotris marmorata*	Malaysia	KT022088.1	9,951
2	*Oxyeleotris marmorata*	USA	AY722177.1	9,951
3	*Oxyeleotris marmorata*	Indonesia	KU692726.1	9,935
Sample code	OMS3			
1	*Oxyeleotris marmorata*	Indonesia	KU692726.1	100
2	*Oxyeleotris marmorata*	Cambodia	EF609424.1	100
3	*Oxyeleotris marmorata*	Vietnam	MH721190.1	99

Population structure analysis of Southeast Asia using mtDNA revealed multiple haplotypes, some of which were widely distributed while others were more limited. Molecular analysis of variance (AMOVA) shows that the differences between and within populations are significant, but the regional differences are small, indicating that genetic differentiation is not completely determined by geographical factors. Some populations (such as those in Ayutthaya, Dongnai and Sabah) have significant genetic differences, while populations in other regions such as Sarawak, Indonesia and western Malaysia are more similar. This reflects complex connectivity and isolation patterns.

5.3 The role of ecological isolation and gene flow in the genetic structure of species

Ecological isolation and gene flow are the key factors shaping the genetic structure of *O. marmorata*. The high genetic diversity within the population and the lack of obvious population boundaries indicate that gene mobility is widespread, which may be the result of the joint promotion of natural diffusion and human migration (such as aquaculture) (Syaifudin et al., 2021). This gene flow helps maintain cross-regional genetic connectivity and reduces the possibility of local genetic differentiation.

According to genetic analysis, due to ecological isolation or diffusion barriers, social populations show obvious genetic differentiation. Due to geographical or ecological barriers restricting gene flow, the populations of Ayutthaya, Dongnai and Sabah showed greater genetic differences (Ha et al., 2011). Gene flow usually helps promote genetic homogenization, but ecological isolation in specific regions may lead to the emergence of different genetic lineages, affecting the genetic structure and adaptation potential of snailfish.

6 Ecological Adaptation Mechanism

6.1 The influence of factors such as water quality, habitat and climate on the physiology of species

The *O. marmorata* has remarkable physiological flexibility and can adapt to changes in water quality and salinity. The snailfish is mainly a freshwater species. It can help snailfish adapt to the Marine environment by up-regulating the proteins and enzymes related to osmotic regulation in the gills (such as Na^+/K^+ -ATPase and $Na^+:K^+:2Cl^-$ cotransporter). When salinity increases, maintaining ionic balance and plasma osmotic pressure (Chew et al., 2009). The *O. marmorata* also prevents the accumulation of ammonia by activating glutamine synthase in the liver and converting ammonia, thus enabling the *O. marmorata* to survive long-term exposure to the air. This process helps marble goby cope with fluctuations in oxygen levels and short-term exposure.

Environmental factors have a significant impact on the metabolism of *O. marmorata*. When foraging at night, the oxygen consumption of *O. marmorata* increases. The excretion of ammonia is closely related to foraging and peaks in the early morning. Resting metabolism is mainly affected by the daily cycle and not by ammonia metabolism (Lim et al., 2020). These physiological characteristics enable marble goby to effectively manage energy and waste in different habitats.

6.2 Physiological and behavioral mechanisms for adapting to different environments

Marble goby adapts and survives in various environments through physiological and behavioral patterns. During the transition from freshwater to seawater, marble goby can perform low-permeability regulation. The levels of osmotic regulatory proteins in the gills increased, and the contents of osmotic substances in the tissues (such as free amino acids and glutamine) increased (Chew et al., 2009). When exposed to the air, marble goby can avoid the toxic accumulation of waste by increasing the activity of glutamine synthase in the liver to convert ammonia into glutamine and reduce the excretion of ammonia and urea (Jow et al., 1999).

From a behavioral perspective, the *O. marmorata* preys at night, and its growth and metabolic rhythms are closely related to the light-dark cycle. The oxygen consumption and metabolic rate of marble goby reach their peak during nocturnal activities, which can support the foraging strategy of marble goby. The activity habit of the marble goby, which forages at night and rests during the day, can enhance energy efficiency and reduce the risk of being preyed upon. Daytime water quality renewal can maintain water quality suitable for the metabolic process of snailfish.

6.3 Relevant genes, proteins and their functions during the adaptation process

The ecological adaptation of marble goby depends on some key molecular components in the body, namely the two subunits of Na^+/K^+-ATPase α (nkaα1 and nkaα3), which are upregulated in the gills of marble goby during the process of seawater adaptation. When exposed to a high-salinity environment, the transcriptional and protein levels of nkaα1 and nkaα3 significantly increased, thereby enhancing the ability of snailfish to regulate ion transport and maintain homeoequilibrium to adapt to the environment (Pang et al., 2020). The $Na^+:K^+:2Cl^-$ cotransporter (NKCC) and transmembrane receptor-like chloride channels in apical cystic fibrosis were also upregulated, further supporting the adaptive mechanism of osmotic regulation.

From a behavioral perspective, the marble goby is a nocturnal ambush predator, and its growth and metabolic rhythms are closely related to the light-dark cycle. During nocturnal activities, the oxygen consumption and metabolic rate of the marble goby reach their peak, which is used to support the foraging strategy of the marble goby. The habit of black-headed fish foraging at night and resting during the day can improve energy efficiency and reduce the risk of being preyed on. Daytime water quality renewal can maintain water quality suitable for the metabolic process of snailfish.

7 The Influence of Human Activities on The Distribution and Adaptation of *O. marmorata*

7.1 Threats to species caused by water pollution, habitat loss and other human activities

Human activities such as water pollution and habitat loss seriously threaten the survival of *O. marmorata* populations. Due to human intervention, *O. marmorata* have been introduced into new habitats, which may damage the local ecosystem and threaten the diversity of local fish species. The changes in habitat quality and structure may have adverse effects on *O. marmorata* and other aquatic species (Lestari et al., 2019). Pollution caused by agricultural runoff, industrial wastewater and urban development will deteriorate water quality and affect the growth and reproductive success of marble goby.

The loss of habitats, especially those caused by dam construction, land reclamation and other habitat modification activities, will lead to the segmentation of populations and the reduction of suitable foraging, breeding and habitat environments. These changes may lead to a reduction in population size, increase the vulnerability of species to stress factors such as diseases and predation, and thereby further threaten the long-term survival of species.

7.2 Potential impacts of fishery development and human habitat construction on the distribution of *O. marmorata*

The main factor influencing the distribution and population dynamics of *O. marmorata* is fishery activities. In the study of Sempor Reservoir, it was found that the fishery development speed in the central region was five times that of the export area, and fishery activities were the main cause of death of snailfish in highly developed areas (Lestari et al., 2019). Overfishing may lead to a reduction in the population size of *O. marmorata*, alter their growth age and body structure, affect genetic diversity, and influence their ability to adapt to environmental changes.

The construction of human habitats, such as reservoirs and other water resource management facilities, can promote the expansion of new growth areas for *O. marmorata* and may also lead to *O. marmorata* becoming invasive species, thereby threatening local biodiversity. On the contrary, overexploitation and habitat destruction may also limit the distribution range of *O. marmorata*, reduce the richness of *O. marmorata* species, and highlight the complex interrelationship between human activities and species distribution.

7.3 Suggestions for the maintenance and management strategies of *O. marmorata*

The cultivation, protection and effective reproduction of *O. marmorata* require finding a balanced approach. Address the risks of overdevelopment and assess the possible ecological impacts of introducing new habitats. Population control measures were taken and targeted fishing was carried out within a specific body length range (13.38-17.30 cm), which can help manage the population size and reduce the negative impact on the local fish community (Lestari et al., 2019). Keep the catch rate below the sustainable threshold (such as $E \leq 0.5$) to prevent overfishing and ensure the long-term reproduction of *O. marmorata*.

In terms of fish conservation, protecting and restoring habitats is also very important for maintaining healthy populations. Monitoring water quality, regulating pollutant emissions and protecting natural habitats can effectively mitigate the adverse effects brought about by human activities. Combining the enhancement of public awareness with the participation of stakeholders can sustainably manage and protect the ecosystem and habitat of *O. marmorata.*

8 Future Research Directions

8.1 Further explore the application of genomics and molecular biology in the research of marble goby

The latest advancements in genomics and molecular biology offer significant opportunities for a deeper understanding of marble goby. With the help of high-throughput sequencing technology and genome assembly, genetic diversity can be revealed, adaptive genes identified, and the evolutionary relationships within and outside the population can be revealed. These technical methods, similar to the research applications on other species, can detect gene regions affected by selection pressure and help identify genetic markers related to key physiological and ecological characteristics, which is crucial for the implementation of basic research and breeding programs (Gao et al., 2018).

In future research, researchers can combine genomic data with ecological and physiological studies to explore the molecular mechanisms by which bamboo snappers adapt to different environments. The development of more genomic resources, such as annotated reference genomes and transcriptome data, can provide strong support for the study of gene expression, epigenetic regulation and protein function. These tools are also helpful for identifying candidate genes related to stress resistance, growth and reproduction, and are very important in molecular-assisted selection and conserved genetics (Kelley et al., 2016).

8.2 The relationship between ecological adaptation and environmental changes

The adaptation of *O. marmorata* to changes in their growth environment can be used to predict their responses to habitat changes and climate changes. In some studies of snappers, ecological adaptation is usually the result of the combined effect of genetic diversity and phenotypic plasticity, which enables snappers to survive in a constantly changing environment. Genomic studies can explain the genetic basis of local adaptation. Combined with previous population events (such as population contraction and expansion), analyze how to shape the current genetic structure of snailfish and its adaptation potential (Cortés et al., 2020).

In future research, the interaction between environmental factors and genetic variations can be further explored, and how external factors affect the physiological and behavioral characteristics of marble goby can be investigated. Long-term monitoring and experimental research can provide an in-depth understanding of the adaptability of *O. marmorata* to environmental stress, and can predict the future distribution and aquaculture survival ability of *O. marmorata* populations under different climate change scenarios (Lim et al., 2020).

8.3 Conservation measures and sustainable species management

The combination of genomics and conservation planning is of great significance in the management of marble goby farming. Genomic data can be used to assess the genetic diversity of species, identify different population units and monitor the implementation effects of conservation measures. Fish conservation strategies should give priority to ensuring the maintenance of genetic diversity, protecting major habitats, and reducing the threats of overexploitation and habitat degradation. The establishment of fish fry breeding bases, genetic breeding programs and population monitoring can also be applied to marble goby, which can support the sustainable development of wild and farmed marble goby populations (Ruiz-Mondragón et al., 2024).

Sustainable management will also benefit from predictive models that combine genomic, ecological and environmental data, helping researchers make more accurate decisions. With the help of "big data" technologies including machine learning methods, complex data can be better processed and the effectiveness of protection and management strategies can be enhanced. The collaboration among geneticists, ecologists and resource managers plays a crucial role in the long-term survival and sustainable utilization of snakfish (Neophytou et al., 2022).

9 Concluding Remarks

O. marmorata is native to China and was later introduced to several regions in Southeast Asia, such as Indonesia. marble goby have established stable populations in freshwater systems, such as Sempor Reservoir and Tondano Lake. The introduction of marble goby and the spread of fish fry have changed the structure of fish communities in various regions. The feeding behavior and competitive advantage of marble goby may have an impact on the local biodiversity. Bamboo shoots and shellfish have strong ecological adaptability and can reproduce and grow in different habitats with a relatively fast growth rate. It is gradually taking the dominant position in the new environment. As nocturnal ambush predators, marble goby have a relatively high metabolic rate when foraging at night, and their foraging and metabolic rhythms are closely related to the diurnal cycle. The preference of marble goby for acidic foods can affect their foraging behavior and dietary adaptation in different environments. All these reflect the ecological diversity of the marble goby.

Some progress has been made in the research of the biology and ecology of *O. marmorata* at present. However, issues such as reproductive difficulties, population control and ecological impacts still need to be further explored. The mortality rate of artificially farmed juvenile fish is relatively high, and effective farming strategies are needed. Solve these problems and promote sustainable aquaculture and management. Due to human overfishing and habitat changes, continuous monitoring and flexible management of the growth of marble goby are of great significance for preventing overfishing and maintaining ecological balance. Conducting molecular physiological research on species adaptation mechanisms is conducive to formulating more effective conservation strategies and fishery management methods. In addition to the understanding of the genetic diversity, reproductive biology and environmental tolerance of the *O. marmorata* species, targeted intervention measures should be taken in a timely manner when problems are identified to ensure the sustainability of both wild and farmed *O. marmorata* populations.

Future research can focus on the comprehensive study of genomics, molecular biology and ecology. Exploring the hair adaptation and diffusion mechanisms of *O. marmorata*, and studying the gene expression, protein function and physiological response to environmental stress of *O. marmorata* can help researchers better understand the adaptability and survival resilience of *O. marmorata*. The current research achievements are of great significance for improving breeding techniques, optimizing breeding methods and reducing ecological impacts. Ecological monitoring, population models and the interactions among various stakeholders balance the relationship between fishery economic benefits and local biodiversity conservation. Scientific exploration and flexible management provide strong support for the sustainable development and protection of marble goby.

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Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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