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Exploration of Marine Biodiversity Based on Molecular Biology

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Abstract The global sea area is vast, and in order to protect marine biodiversity and maintain the sustainable development of marine biological resources, it is necessary to deepen the understanding and exploration of marine biodiversity. The application of molecular biology technology in marine biology and biological oceanography began in the mid-1980s. As a powerful means, this technology can be applied to the analysis of marine biodiversity. In recent years, this technology has developed rapidly both domestically and internationally. This review provides an overview of various methods of molecular biology technology and analyzes its significance in exploring marine biodiversity through case studies. It is hoped that a comprehensive understanding of molecular biology technology can provide theoretical reference for marine biodiversity conservation.

Keywords Molecular biology; Genomics technology; Biodiversity

Diversity is one of the fundamental characteristics of life and a guarantee of ecosystems. Marine biodiversity is a core component of marine ecosystems, and its protection and management are crucial for global ecological security and human health. However, the biodiversity in the ocean is multi-level and multidimensional, and its exploration requires the collaborative application of various scientific and technological means. In recent years, with the rapid development of molecular biology technology, exploring marine biodiversity based on molecular biology has become one of the most important means to explore marine biodiversity.

Molecular biology techniques include various techniques such as DNA barcoding, genomics, systematics, transcriptomics, and proteomics, which can assist in the in-depth exploration and understanding of marine biodiversity in this review. For example, DNA barcode technology can quickly identify species in the ocean, playing a crucial role in the discovery and identification of marine biodiversity; Techniques such as genomics, transcriptomics, and proteomics can reveal the genomic and metabolic characteristics of marine organisms (Allard and Moseley, 2019); Systematics can reveal the genetic relationships between different marine organisms, which is of great significance for understanding the evolutionary history and diversity of marine organisms.

However, molecular biology technology also faces some challenges in exploring marine biodiversity. Different methods for DNA extraction and sample processing for marine organisms can affect the application effectiveness of molecular biology technology. The integration of different molecular biology technologies also requires standardization and quality control. Therefore, this review explores and improves the application of molecular biology techniques in marine biodiversity exploration, in order to better understand and protect marine biodiversity. This review will explore the relevant technologies, applications, case studies, challenges, and future directions of marine biodiversity exploration based on molecular biology, and provide scientific basis and reference for the protection and management of marine biodiversity.

1 Overview of Marine Biodiversity Exploration Techniques Based on Molecular Biology

Molecular biology technology is a discipline that explores biological issues at the molecular level, including various technical means such as DNA barcoding, genomics, systematics, transcriptomics, and proteomics. DNA barcode technology is a species identification method based on specific DNA sequences (Figure 1). The target sequence is amplified by PCR, and then sequenced and compared using sequencing technology to determine the

identity of the species. DNA barcode technology can quickly and accurately identify species. Genomics technology can reveal the characteristics of the genome structure, size, composition, and variation of organisms. Exploring the genome of marine organisms can reveal genetic differences between different species and the evolutionary history of gene families, which is of significance for understanding the evolution and phylogeny of marine organisms. Systematics is a discipline that explores the phylogenetic relationships between different species. By comparing the DNA or protein sequences of different species, a phylogenetic tree is constructed to showcase the phylogenetic relationships between different species, as well as the taxonomic and evolutionary history of marine organisms. Transcriptomics technology is used to indicate the gene expression status of organisms under specific conditions, including gene expression levels and patterns. The transcriptomic exploration of marine organisms has led to different adaptations and response mechanisms in different environments (Bloch and Guigues, 2014). Proteomic techniques can reveal the types and quantities of proteins in organisms, as well as the interactions and regulatory relationships between proteins.

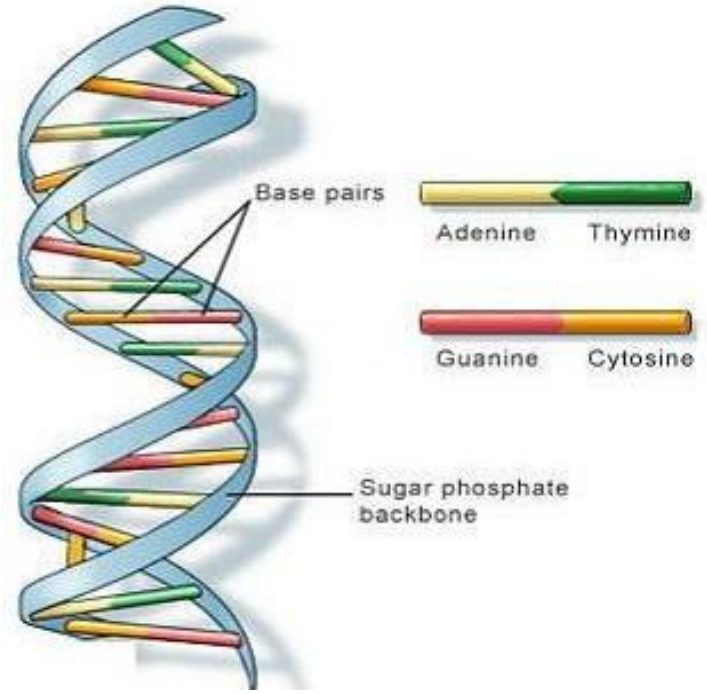

Figure 1 DNA barcoding sequence recognition (Bloch and Guigues, 2014)

2 Application of Marine Biodiversity Exploration Technology Based on Molecular Biology

2.1 Species Identification and Discovery

DNA barcode technology can quickly and accurately identify the species identity of marine organisms. At the same time, by analyzing DNA barcoding of marine organisms, new species and subspecies can be discovered, enriching the knowledge of marine biodiversity. DNA barcode technology is a species identification method based on specific DNA sequences, which amplifies the target sequence through PCR and then uses sequencing technology for sequence identification and alignment to determine the identity of the species. Specifically, the first step is to select a specific DNA sequence as the 'barcode', which is usually a short nucleic acid sequence with high mutation rate and species specificity, representing the uniqueness of the species. Amplify the target sequence through PCR to obtain DNA fragments. Next, the PCR products were sequenced to obtain the DNA sequence. Finally, sequence alignment software is used to compare DNA sequences with known species DNA sequences in the database to determine the identity of the species (Féral, 2002).

For marine organisms, traditional species identification methods have significant limitations due to their wide variety and similar morphology. DNA barcode technology can quickly and accurately identify the species identity of marine organisms. By analyzing DNA barcoding of marine organisms, new species can also be discovered,

thereby enriching the knowledge of marine biodiversity. Therefore, DNA barcode technology has become one of the indispensable technological means in exploring marine biodiversity.

2.2 Revealing the diversity and distribution patterns of marine organisms

Specifically, genomics technology can reveal the genomic structure, size, composition, and variation of marine organisms (Thakur et al., 2008). By comparing and analyzing the genomes of different marine organisms, we aim to understand their genetic differences and the evolutionary history of gene families. At the same time, genomics technology can also demonstrate the gene functions and metabolic pathways of different marine organisms, which is of great significance in understanding the ecological niche of marine organisms (Figure 2). In terms of phylogenetic technology in the phylogenetic relationship and evolutionary history of marine organisms, by comparing and analyzing the DNA and protein sequences of different marine organisms, a phylogenetic tree of species can be constructed to identify the phylogenetic relationships between different marine organisms. These exploration results can further help people understand the evolution and phylogeny of marine organisms (Figure 3), and can also better explain the taxonomy of marine organisms.

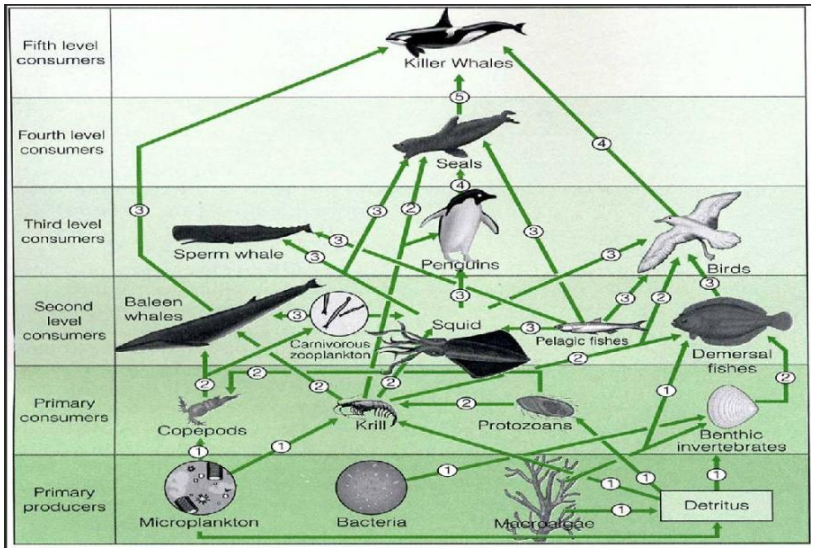

Figure 2 Ecological niche of marine mammal

Figure 3 Evolution of marine organisms

Transcriptomics technology refers to the expression of genes under specific conditions, including their expression levels and patterns. Analyze the gene expression of different marine organisms in different environments, and understand the diversity and distribution patterns of marine organisms. For example, an investigation found that in marine surface waters, the transcriptome responses of different species exhibit significant differences, and the transcriptome response patterns of different species reflect their functional differentiation in different ecological niches.

2.3 Assessing the impact of environmental changes on marine biodiversity

The exploration technology of marine biodiversity based on molecular biology can understand the impact of environmental changes on marine biodiversity (Carugati et al., 2015). For example, analyzing the gene expression of marine invertebrates in different environments through transcriptomics technology can reveal the impact of environmental pressure on marine biodiversity, providing scientific basis for the protection and management of marine organisms. A previous study reported the impact of temperature rise on corals. Transcriptome analysis was conducted on two coral species, and it was found that under high temperature conditions, the gene expression pattern of corals (Figure 4) changed significantly, with some genes expressing significantly more while others expressing significantly less. These genes are involved in biological processes such as coral immune response, redox reaction, and signal transduction. These results indicate that corals adjust their gene expression patterns to adapt to changing environments under high temperature conditions.

In addition, another study reported the effect of acidification on mussels (Figure 5). This study conducted transcriptome and metabolomic analysis on mussels and found that under acidification conditions, the metabolic pathways and gene expression patterns of mussels underwent significant changes. Under special acidification conditions, the expression level of carbonic anhydrase genes in mussels significantly increases, thereby enhancing their tolerance to acidic environments. These results indicate that under acidification conditions, mussels adjust their metabolic pathways and gene expression patterns to adapt to changing environments. The exploration technology of marine biodiversity based on molecular biology can reveal the impact of environmental changes on marine biodiversity, especially through the analysis of gene expression and metabolic pathways of marine organisms, the impact of environmental pressure on marine biodiversity can be revealed.

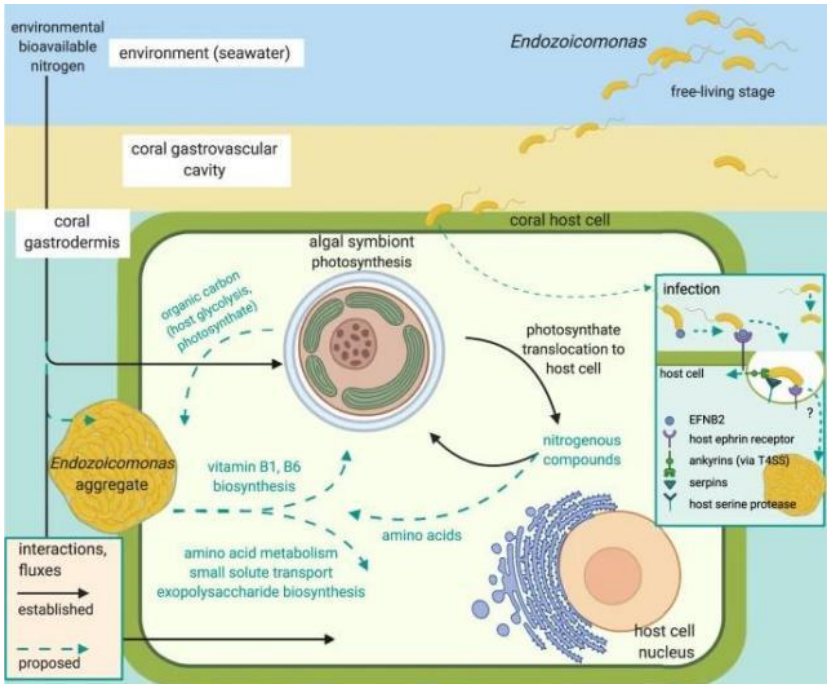

Figure 4 Gene expression pattern of coral

Figure 5 Mussels in marine life

3 Cases of Molecular Biology Technology in Exploring Marine Biodiversity

3.1 16S rRNA gene sequencing technology

The exploration of marine biodiversity based on molecular biology techniques has been applied in many fields, including the exploration of marine microbial diversity. Marine microorganisms are one of the most important components in marine ecosystems, playing a crucial role in the balance and stability of marine ecosystems. However, due to the large number and variety of marine microorganisms, their exploration has always faced difficulties.

In recent years, a molecular biology based method for exploring marine microbial diversity, 16S rRNA gene sequencing technology, has provided new ideas and methods for exploring marine microorganisms. The 16S rRNA gene is a common marker gene in bacteria and archaea, and its sequence is highly conserved and variable among different species, making it suitable for identifying and classifying microbial species. By PCR amplification and sequencing of 16S rRNA genes in marine microbial samples, the diversity and distribution of marine microorganisms can be understood, and the structure and function of marine microbial communities can be revealed.

For example, a study conducted 16S rRNA gene sequencing analysis on marine microorganisms in Antarctica and found that there is rich microbial diversity in the Antarctic waters, including bacteria, archaea, and eukaryotic microorganisms. At the same time, the study also found that microbial diversity is closely related to marine environmental factors, such as temperature, salinity, and nutrients (Natalie et al., 2023). Another study conducted 16S rRNA gene sequencing analysis on Pacific marine microorganisms and found significant geographical differences in their diversity (Figure 6) and distribution, as well as significant differences in microbial community structure and function in different sea areas. These exploration results indicate that 16S rRNA gene sequencing technology can reveal the diversity and distribution patterns of marine microorganisms, providing important information for better understanding the ecological significance of marine microorganisms.

Figure 6 Marine microorganisms

3.2 Transcriptomic analysis of environmental pressure in marine invertebrates

A transcriptomic analysis was conducted on marine invertebrates (Figure 7) to understand their response mechanisms to environmental pressure. This experiment collected and processed invertebrate samples from different sea areas, and obtained transcriptome data containing gene expression information. Analysis has found that marine invertebrates activate different gene expression patterns and metabolic pathways to adapt to changing environments when facing different environmental pressures (Xiong et al., 2022). This result provides important information for this review to better understand the environmental adaptation mechanisms and ecological functions of marine organisms.

Figure 7 Marine invertebrate-tube worm

4 Challenges and Future Directions of Molecular Biology Technology in Exploring Marine Biodiversity

The application of molecular biology technology in marine biodiversity exploration has achieved many results, but at the same time, it also faces some challenges. The complexity of the marine environment and the difficulty of sample collection are one of the main challenges faced by molecular biology techniques in exploring marine biodiversity. The widespread distribution and large quantity of marine organisms, and some species inhabit deep sea or polar environments, requiring a significant amount of time and effort to collect and process samples. In addition, there are often some factors that hinder the application of molecular biology techniques in marine biological samples, such as small biological volume, poor DNA quality, and easy degradation of RNA.

Molecular biology technology requires a large amount of data analysis and processing in the exploration of marine biodiversity, therefore standardization and quality control are very important. At present, there is no comprehensive standardized method and quality control procedure, which also leads to certain uncertainties and

errors in the exploration of marine biodiversity using molecular biology technology. The exploration of marine biodiversity requires the integration of multiple molecular biology technologies, such as DNA barcoding, transcriptomics, proteomics, etc. This requires scientists to possess multiple skills and knowledge, and to consider how to integrate data from different technologies in order to obtain more comprehensive information and accurate conclusions. Molecular biology techniques have generated a large amount of data in the exploration of marine biodiversity, which can be used to evaluate the health status, species quantity and distribution, ecological function, and other aspects of marine ecosystems. However, more exploration and exploration are still needed to transform these data into practical protection and management measures.

In the future, the application of molecular biology technology in marine biodiversity exploration will continue to develop. Just like single-cell genomics technology can be used to explore the single-cell genome and metabolic function of marine microorganisms; Artificial intelligence and machine learning technologies can be used to process large-scale data, improve the accuracy and efficiency of data analysis and interpretation; Gene editing technology can be used to explore the functional genes and ecological functions of marine organisms. The application of these new technologies will promote the further development and application of molecular biology technology in marine biodiversity exploration (Cribb et al., 2021).

5 Summary and Outlook

Molecular biology is a discipline that explores the molecular structure, function, and genetic information transmission of living organisms, while marine biodiversity exploration explores the diversity and ecological functions of species and quantities in the ocean. Molecular biology technology can reveal information on species identification, genetic diversity, evolutionary history, and ecological functions of marine organisms by analyzing molecular information such as DNA, RNA, and proteins. Therefore, molecular biology techniques play a crucial role in exploring marine biodiversity.

The application of molecular biology technology in the exploration of marine biodiversity has achieved many meaningful results (Nicolas et al., 2021). DNA barcode technology can quickly and accurately identify marine fish species, metagenomics technology can explore the metabolic pathways and ecological functions of marine microorganisms, genomics and transcriptomics technology can explore the evolutionary history and phylogenetic relationships of deep-sea organisms, proteomics technology can explore the metabolic pathways and physiological mechanisms of marine algae, Transcriptomics techniques can explore the response mechanisms of marine invertebrates to environmental pressure (Liang et al., 2002).

There is still great potential for development in the application of molecular biology technology in the exploration of marine biodiversity. With the continuous updating and improvement of technology, the application of molecular biology technology in marine biodiversity exploration will be more extensive and in-depth in the future. By gaining a more accurate and comprehensive understanding of marine biodiversity and functions, people can better protect and manage marine ecosystems, maintain marine ecological balance, and promote human well-being.

This review mainly explores the application of molecular biology technology in marine biodiversity exploration, and analyzes its application and development trends in DNA barcoding, metagenomics, genomics, and other fields. Exploration has found that molecular biology technology can provide fast and efficient methods for identifying marine organisms and resource management, which can deeply explore the metabolic pathways, evolutionary history, and ecological functions of marine organisms. At the same time, it can also evaluate the health status, species quantity and distribution, ecological functions, and other aspects of marine ecosystems. In addition, molecular biology technology still faces challenges in the exploration of marine biodiversity, such as sample collection and processing, standardization and quality control, and integration of different technologies.

Authors' contributions

WJN is the main author of this review, responsible for collecting relevant literature and writing the first draft of the paper; WW is the project leader and participates in the analysis and organization of literature materials; CLL participated in the revision of the paper. All authors have read and agreed to the final text.

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