

protected area development and fisheries management measures. Incorporating these strategies into national aquaculture development plans will help maintain genetic diversity in both wild and cultured populations and provide a solid foundation for future breeding improvement.

Future research on grouper genetic diversity should increasingly rely on high-throughput genomic technologies and integrate genetic variation with production traits and adaptive potential. Whole-genome resequencing and reduced-representation methods such as RAD-seq and ddRAD can provide high-density SNP data for fine-scale population structure analysis, detection of selection signals, and genomic selection of traits such as growth, disease resistance, and environmental adaptability—approaches that have already proven successful in species such as salmonids. At the same time, low-cost, species-specific genotyping tools (e.g., targeted SNP panels) suitable for small and medium-sized aquaculture enterprises should be developed, and the effects of different detection strategies (e.g., sequencing depth and marker density) on genetic diversity and kinship assessment should be systematically evaluated. At the ecological level, integrating population genomics with marine environmental factors and tagging technologies can further optimize the delineation of management units, particularly for heavily exploited species such as Nassau grouper and brown grouper. In addition, incorporating genetic data into stock enhancement evaluation, studies of interactions between cultured and wild populations, and emerging biotechnologies (e.g., genomic selection, surrogate broodstock technology, and gene editing) will help develop breeding and conservation strategies that balance production efficiency with genetic security. Ultimately, such integrated approaches will ensure the long-term health and sustainable utilization of grouper germplasm resources.

Conflict of Interest Disclosure

The author affirms 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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