grouper (*E. coioides*), Malabar grouper (*E. malabaricus*), giant grouper (*E. lanceolatus*), and yellow grouper (*E. awoara*). Additionally, species such as brown-marbled grouper, camouflage grouper, and coral trout also hold high economic value in regional aquaculture (Das et al., 2021). In recent years, hybrid breeding has developed rapidly; for instance, hybrids between giant grouper and orange-spotted grouper exhibit significant advantages in growth and stress resistance. However, differences in genetic background and pedigree stability among species and hybrids may lead to germplasm admixture and distortion of resource information if standardized classification and genetic monitoring are lacking. Therefore, systematic classification and phylogenetic organization of germplasm resources form the foundation for genetic evaluation and breeding utilization.

2.2 Distribution characteristics of different geographic populations

Groupers are widely distributed in tropical and subtropical seas, and in China they are mainly found in the South China Sea, East China Sea, and Taiwan Strait. Although their distribution range is broad, genetic studies indicate that natural populations are not randomly mixed but generally exhibit significant geographic structure (Chen et al., 2025). This differentiation is mainly influenced by ocean current systems, strait barriers, island distribution, and historical sea-level fluctuations during the Pleistocene, as well as species-specific dispersal capacity and reproductive behavior (Yang et al., 2022; Fadli et al., 2023).

Taking orange-spotted grouper (*E. coioides*) as an example, microsatellite analyses have revealed significant genetic differentiation among populations from China, Malaysia, and Indonesia, while populations within China's coastal waters show relatively low differentiation. This suggests the formation of regional genetic structure at large spatial scales, with some degree of gene flow at local levels. Further studies indicate that this species may comprise two major evolutionary lineages, likely shaped by marginal sea isolation and Pleistocene sea-level changes (Chen et al., 2025). Similarly, yellow grouper (*E. awoara*) exhibits relatively high genetic diversity, but the Beibu Gulf population shows distinct characteristics, with the Qiongzhou Strait and Taiwan Strait acting as important barriers in its genetic differentiation (Yang et al., 2022).

At broader spatial scales, different grouper species exhibit diverse patterns of genetic structure. Studies in the Indo-Malay Archipelago show that some species display clear geographic differentiation, whereas others exhibit genetic homogeneity, closely related to larval dispersal capacity and habitat dependence (Fadli et al., 2023). In addition, regional genetic structure and low effective population sizes have been observed in species such as Nassau grouper and brown grouper in the Atlantic (Vaini et al., 2021). Notably, in aquaculture systems, frequent translocation of juveniles and artificial breeding have led to increasing mixing of geographic populations, gradually weakening original genetic structures. While this improves resource utilization efficiency, it also introduces risks of genetic contamination and loss of local adaptation. Therefore, both natural geographic structure and human intervention must be considered in germplasm utilization to ensure genetic compatibility and resource security.

2.3 Current status and challenges of germplasm resources

At present, grouper germplasm resources are characterized by "rich diversity but uneven utilization." Wild populations are highly diverse with complex genetic backgrounds, providing important genetic sources for breeding; however, aquaculture mainly relies on a limited number of dominant species and their hybrids (Ybanez and Gonzales, 2023). Although Asia contributes over 90% of global production, germplasm utilization is relatively concentrated. While this improves production efficiency, it also exacerbates issues such as a narrow genetic base and germplasm homogenization. Under long-term artificial selection and closed breeding systems, some cultured populations have exhibited genetic degeneration, including reduced growth performance, weakened stress resistance, and increased disease susceptibility (Li, 2022; Sonesson et al., 2023).

From a genetic perspective, these problems mainly arise from founder effects, genetic drift, and the accumulation of inbreeding. Studies have shown that in species such as orange-spotted grouper, kelp grouper, and sevenband grouper, cultured populations often experience the loss of rare alleles and reduced allelic richness. Even when heterozygosity does not change significantly, their genetic potential may still decline. In addition, insufficient