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Challenges and Progress of Grouper Aquaculture in Asia: A Review

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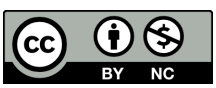

ABSTRACT. Asia is widely recognized for its grouper aquaculture. China (65%), Taiwan (17%), and Indonesia (11%) together account for 93% of global grouper production. This study recorded 48 species, and 16 hybrids were used in Asian aquaculture. The conservation status of cultured grouper species is 67% least concern, 17% data deficient, 10% vulnerable, and 2% critically endangered, endangered, and near threatened. Most Asian countries face issues such as (1) lack of hatcheries, (2) poor seedstock, (3) poor broodstock quality, (4) lack of financial and technical support, (5) trash fish and accessibility to fish pellets, (6) poor water quality, (7) diseases, and (8) capture-based aquaculture. These issues, combined with overfishing, contribute to a decline in grouper productivity and their wild population. The decline has alarmed experts and conservationists looking into the causes and potential remedies to this problem. Some management strategies mentioned in this paper include: (1) closed season during spawning aggregation, (2) establishing more marine protected areas (MPAs), particularly the no-take marine reserve, (3) non-consumptive utilization of groupers (eco-tourism) and (4) establishing more full-cycle grouper aquaculture. The results of this study suggest that implementing these strategies could be an effective means of addressing the issue of grouper production and that additional research is required to determine the most effective method of addressing this problem. The findings of this study have significant implications for the development and sustainability of grouper aquaculture and highlight the need for further research in this area.

Keywords: *Aquaculture, conservation status, full-cycle aquaculture, grouper, MPA*

INTRODUCTION

Groupers are one of the most species-rich percoid clades, comprising 167 species traditionally divided into 15 genera (Félix-Hackradt et al., 2022). These genera include Aethaloperca, Alphestes, *Anyperodon, Cephalopholis, Cromileptes, Dermatolepis, Epinephelus, Gonioplectrus, Gracila, Mycteroperca, Paranthias, Plectropomus, Saloptia, Triso,* and *Variola* (Heemstra and Randall, 1993; Ma and Craig, 2018). Groupers are a type of marine fish that belong to the family Serranidae and are widely distributed in tropical and subtropical waters (Jefri et al., 2015). The aquaculture of groupers is an important sector in the aquaculture production portfolios of many countries, especially in Asia (Rimmer and Glamuzina, 2017). The cultivation of groupers has gained immense popularity in recent years due to their high market demand and export potential (Bahri and Jata, 2021).

Farming groupers involve breeding, hatching, and rearing these fish in controlled environments such as ponds, tanks, or cages (Dennis et al., 2020). The aquaculture of groupers has become an important source of income for many farmers and has contributed significantly to the economic growth of several countries (Tran et al., 2017). The success of grouper aquaculture is attributed to developing advanced technologies and techniques for breeding, feeding, and disease management (Liao et al., 2001; Bunlipatanon and U-taynapun, 2017; Kobayashi, 2022). However, there are also challenges associated with grouper aquacultures, such as disease outbreaks, environmental impacts, and market fluctuations (Md Noor and Harun, 2022). Therefore, continuing research and development in this field is crucial to ensure sustainable and profitable grouper aquaculture. According to data provided to the Food and Agriculture Organization (FAO) in 2017, the production of grouper in 2015 amounted to nearly 155,000 tonnes, not including unreported or illegal catches (Rimmer and Glamuzina, 2017). This production had a total value of USD 630 million (Novriadi, 2019). China is the largest producer of grouper, accounting for 65% of the total production (Afero et al., 2010; Rimmer and Glamuzina, 2017). Taiwan and Indonesia are the second and third largest producers, respectively, contributing 17% and 11% to the total production (Megarajan et al., 2022a). Collectively, these three countries account for 93% of the reported production. According to Rimmer and Glamuzina (2017), Malaysia, Philippines, Thailand, Vietnam, Australia, Cambodia, United States of America, and Brazil account for only 7% of grouper production (Figure 1).

The grouper fish is widely recognized as an icon of luxury consumption in Southeast Asian nations and across the globe, owing to its expensive market value (Khasanah et al., 2020). Due to its exquisite flavor and taste, it is one of the most popular seafood choices, especially at high-end Chinese restaurants (Alcantara and Yambot, 2016). The high market demand for groupers has led to developing and enhancing farming strategies (Dennis et al., 2020). This trend gained momentum in Asian countries following the outbreak of diseases in marine shrimps during the late 1980s and early 1990s (Lafferty et al., 2015). In recent years, significant progress has been made in grouper aquaculture. These advancements include implementing larval-rearing techniques aimed at enhancing the growth and survival rates of groupers during the hatchery phase (Ranjan et al., 2022a). Additionally, there has been a focus on developing grouper diets with minimal environmental impact (Lupatsch and Kissil, 2005; Shapawi et al., 2019) and grouper hybrids (Shapawi et al., 2019; Xu and Li, 2021). These efforts are aimed at minimizing the ecological impact of grouper farming and improving the industry's overall sustainability.

There have been few review studies on grouper aquaculture in Asia that have focused on the development and challenges of this undertaking, and there is no current assessment of its status. Among the notable research reviews are Rimmer and Glamuzina

(2017), Pomeroy et al. (2002), and Tookwinas (1989). Given the importance of this species in Asia, it is critical to study the current state of grouper aquaculture in this region. As a result, the purpose of this review paper is to give an up-to-date assessment of the Asian grouper aquaculture industry, with an emphasis on the progress and issues associated with grouper farming in this region.

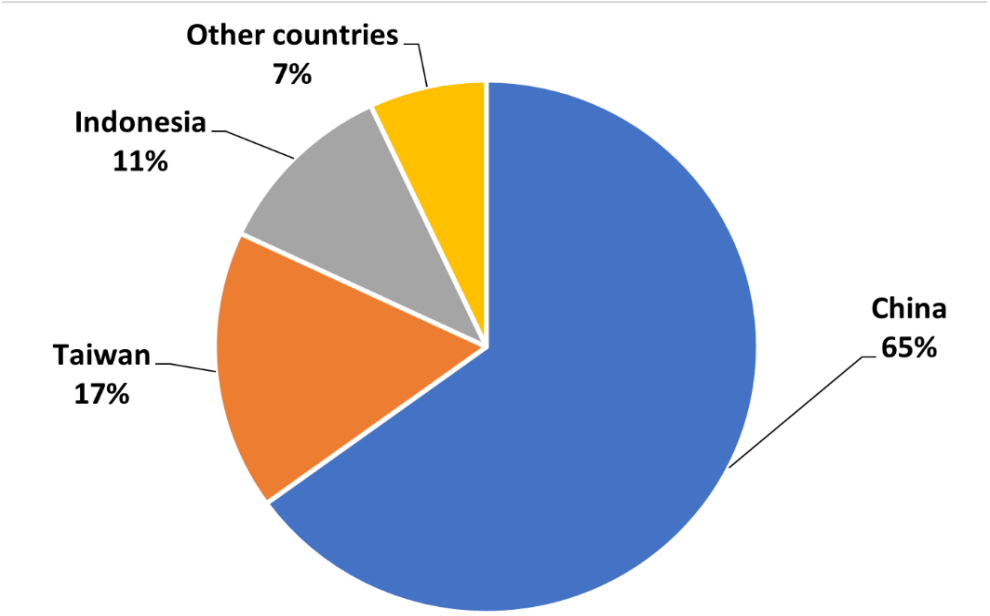

Figure 1. The top three grouper aquaculture producers across the world as of 2015.

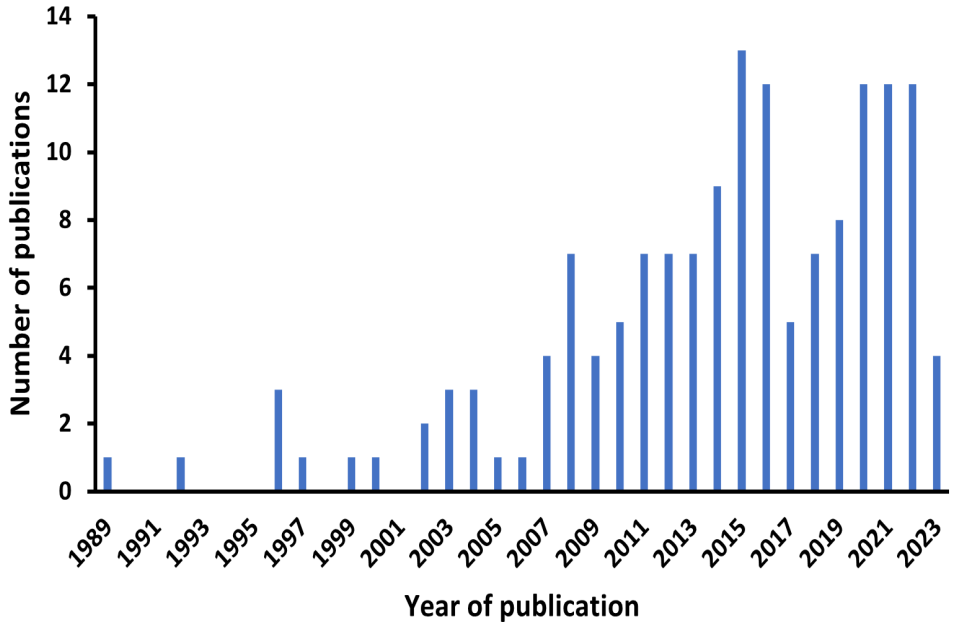

Figure 2. The number of publications generated on grouper studies in Asia from 1989 to 2023.

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Grouper Studies in Asia

The current paper focuses on the existing state of grouper fisheries in the Asian region. The present investigation sourced its data from scholarly databases, including Google Scholar, Elsevier, and Springer, from January 2023 to April 2023. This paper did not incorporate data from unpublished technical papers or theses at the master's or doctoral level. The exhaustive review search yielded 153 published grouper studies from 1989 to 2023. In recent years, there has been a rise in the number of grouper publications in Asia (Figure 2). This trend applies to other fish groups as well (Reverter et al., 2021). The steady increase in published research may be attributed to the emergence of novel sampling techniques and advanced technologies that facilitate the exploration of these fish's genetics, physiology, anatomy, and molecular biology (Dunham, 2023).

Diversity and conservation status

This review paper reveals that out of the 167 known grouper species distributed globally, 48 species, accounting for 28% of the total grouper population, are utilized in aquaculture (Table 1). These grouper species belong to seven genera, namely *Epinephelus* (36 species), *Plectropomus* (4 species), *Cephalopholis* (4 species), *Aethaloperca* (1 species), *Cromileptes* (1 species), *Hyporthodus* (1 species), and *Mycteroperca* (1 species). Moreover, 16 grouper hybrids have been produced, and several of these hybrids have already been used in aquaculture operations (Table 1). The growing number of cultured species and hybrids may be attributed to their high market demand (Dennis et al., 2020). Grouper is widely regarded as a highly sought-after culinary delicacy, particularly in China, known as the largest consumer of this fish species (Khasanah et al., 2020). The high cost of groupers encourages people to engage in grouper farming.

Overfishing is another reason why fish farming or aquaculture has become more popular (Longo et al., 2019). The industrialization of the fishing industry and the increasing global demand for seafood have people taking more fish from oceans, lakes, and rivers than is sustainable (Arlinghaus et al., 2019). Aquaculture is a way to produce fish without putting additional pressure on wild fish populations. Grouper hybridization and full-cycle aquaculture help reduce the overexploitation of grouper in the wild (Mustafa, 2015). Aquaculture of groupers is carried out in tropical and subtropical areas throughout the world, but most production is from Asia, with three countries responsible for an estimated 93% of global production: China (65% of total production), Taiwan Province of China (17%) and Indonesia (11%). In recent years, there have been an increasing number of grouper farms in Asia, primarily because of the rising market demand for this species on a global scale (Loh et al., 2020).

Hybridization in aquaculture has been observed to yield favorable offspring exhibiting desirable phenotypic traits (Liang et al., 2023). This technique has gained popularity in the context of grouper farming as it has the potential to enhance production efficiency (Shapawi et al., 2019). Farmers favor hybrids due to their emergence of advantageous characteristics from the male giant grouper (*E. lanceolatus*), including rapid growth, superior meat quality, and other desirable traits (Nankervis et al., 2022). The current trend in grouper aquaculture is leaning towards cultivating hybrid varieties, owing to their enhanced growth rate and heightened resistance to diseases and parasites (Chuda et al., 2018). The hybridization of *E. fuscoguttatus* and *E. polyphekadion* has led to the formation of the hybrid grouper, which has exhibited superior growth performance compared to its parental species (Xie et al., 2021a). *E. fuscoguttatus* and *E. lanceolatus* were successfully hybridized in Indonesia and are now utilized there in aquaculture (Dennis et al., 2020). According to Huang et al. (2016), it has been recently observed that a certain percentage of hybrid groupers (*E. coioides* x *E. lanceolatus*) exhibit

triploidy, with a prevalence ranging from 7% to 15%. The growth rate of triploid fish was 1.6 times faster than that of diploid hybrids up to 6 months and 1.4 times faster up to 18 months of age.

In this review the conservation status of grouper was noted, 2% of the cultured grouper species is in critically endangered condition, 2% as endangered, 10% as vulnerable, 2% as near threatened, 17% as data deficient, and 67% as least concern (Table 1 & Figure 3). Nassau grouper (*E. striatus*) was listed as critically endangered, and Hong Kong grouper (*E. akaara*) was listed as endangered. According to the International Union for Conservation of Nature (IUCN), the species *E. striatus* and *E. akaara* are classified as endangered due to their significant population decline of approximately 60% over the course of the past three decades (de Mitcheson et al., 2020).

It has been observed that one of the species, namely *E. aeneus*, is listed as near threatened (2%), while five other species, namely *E. bruneus, E. fuscoguttatus, E. marginatus, E. polyphekadion,* and *P. areolatus*, are listed as vulnerable (10%). The declining number of the wild grouper population, especially in Southeast Asia, has an adverse effect on the species conservation status. This trend indicates the serious threats that groupers face on a global scale. The categorizations of "Data deficient" and "Least concern" in the context of species conservation do not necessarily indicate a complete absence of risk (Luiz et al., 2016). While these classifications may suggest a lower level of concern than other categories, such as "Endangered" or "Critically endangered," it is important to note that they do not necessarily guarantee the safety of a given species. It is critical to remember that most of the species in this study lack a substantial amount of high-quality data. Moreso, to have a clear perspective on the state of specific fisheries, rigorous study and data collection must be done.

Numerous conservation strategies have been implemented to aid in preserving the grouper species. One such approach involves the establishment of closed seasons during which fishing activities are prohibited (Piah et al., 2018). Closed seasons should coincide with the spawning season of grouper (Ohta and Ebisawa, 2015). The

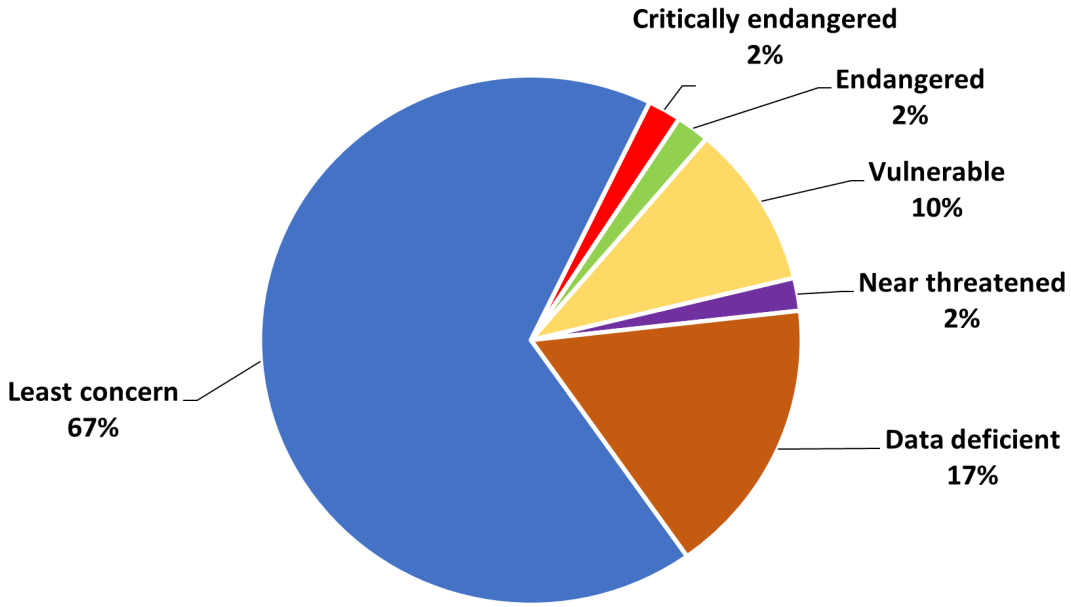

Figure 3. The conservation status of cultured grouper in Asia.

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		Seedstock			
	Common name	**Wild capture**	**Hatchery**	**Conservation Status**	**Reference**
Epinephelus spp.					
E. aeneus	White grouper	Yes	No	Near threatened	Evliyaoğlu et al., 2019
E. akaara	Hong Kong grouper	Yes	Yes	Endangered	Wang et al., 2016
E. amblycephalus	Banded grouper	Yes	Yes	Least concern	Tucker et al., 2016
E. areolatus	Areolate grouper	Yes	Limited	Least concern	Rimmer and Glamuzina, 2017
E. awoara	Yellow grouper	Yes	Yes	Data deficient	Rimmer and Glamuzina, 2017
E. bleekeri	Duskytail grouper	Yes	No reports	Data deficient	Dennis et al., 2020
E. bontoides	Palemargin grouper	-	-	Least concern	Rimmer and Glamuzina, 2017
E. bruneus	Longtooth grouper	Yes	Yes-limited	Vulnerable	Kim et al., 2019
E. chlorostigma	Brownspotted grouper	-	-	Least concern	Rimmer and Glamuzina, 2017
E. coeruleopunctatus	Whitespotted grouper	Yes	Yes	Least concern	Rimmer and Glamuzina, 2017
E. coioides	Orange-spotted grouper	Yes	Yes-routine	Least concern	Chen et al., 2018
E. corallicola	Duskyfin grouper	-	Yes	Least concern	Rimmer and Glamuzina, 2017
E. costae	Golden grouper	No	No	Data deficient	Rimmer and Glamuzina, 2017
E. cyanopodus	Speckled blue grouper	-	-	Least concern	Rimmer and Glamuzina, 2017
E. fasciatomaculosus	Rock grouper	Yes	-	Least concern	Frable et al., 2019
E. fasciatus	Blacktip grouper	Yes	Yes-limited	Least concern	Phạm et al., 2022
E. flavocaeruleus	Blue-and-yellow grouper	-	-	Least concern	Rimmer and Glamuzina, 2017
E. fuscoguttatus	Brown-marbled grouper	Yes	Yes-routine	Vulnerable	Rimmer and Glamuzina, 2017
E. howlandi	Blacksaddle grouper	-	Yes	Least concern	Rimmer and Glamuzina, 2017
E. lanceolatus	Giant grouper	Yes	Yes	Data deficient	Nankervis et al., 2022
E. longispinis	Longspine grouper	-	Yes	Least concern	Sen et al., 2019
E. maculatus	Highfin grouper	-	-	Least concern	Rimmer and Glamuzina, 2017
E. malabaricus	Malabar grouper	Yes	Yes	Least concern	Rimmer and Glamuzina, 2017
E. marginatus	Dusky grouper	No	Yes	Vulnerable	Aride et al., 2021
E. merra	Honeycomb grouper	Yes	-	Least concern	Amagai et al., 2020
E. multinotatus	White-blotched grouper	-	-	Least concern	Rimmer and Glamuzina, 2017
E. ongus	White-streaked grouper	Yes	-	Least concern	Rimmer and Glamuzina, 2017
E. polyphekadion	Camouflage grouper	-	Yes-limited	Vulnerable	Rimmer and Glamuzina, 2017
E. quoyanus	Longfin grouper	Yes	Yes	Least concern	Basith et al., 2021
E. sexfasciatus	Sixbar grouper	Yes	-	Least concern	Fadli et al., 2023
E. spilotoceps	Foursaddle grouper	Yes	-	Least concern	Rimmer and Glamuzina, 2017
E. striatus	Nassau grouper	-	Yes-limited	Critically endangered	de Mitcheson et al., 2020
E. tauvina	Greasy grouper	Unclear	No	Data deficient	Rimmer and Glamuzina, 2017
E. trimaculatus	Threespot grouper	Yes	Yes	Least concern	Tucker et al., 2016
E. tukula	Potato grouper	No	Yes	Least concern	Rimmer and Glamuzina, 2017
E. undulosus	Wavy-lined grouper	-	-	Least concern	Rimmer and Glamuzina, 2017
Plectropomus spp.					
P. areolatus	Squaretail coral grouper	-	Yes	Vulnerable	Rimmer and Glamuzina, 2017
P. laevis	Black-saddled coral grouper	Yes	Yes	Least concern	Alcantara & Yambot, 2016
P. leopardus	Leopard coral grouper	Yes	Yes	Least concern	Rimmer and Glamuzina, 2017
P. maculatus	Spotted Coral Grouper	Yes	-	Least concern	Efendi et al., 2020
Cephalopholis spp.					
C. argus	Celestial grouper	-	-	Least concern	Rimmer and Glamuzina, 2017
C. boenak	Chocolate hind	Yes	-	Least concern	Yan et al., 2020
C. formosa	Bluelined hind	Yes	-	Least concern	Rimmer and Glamuzina, 2017
C. miniata	Coral grouper	Yes	-	Least concern	Rimmer and Glamuzina, 2017
Other groupers					
Aethaloperca rogaa	Redmouth grouper	-	-	Least concern	Rimmer and Glamuzina, 2017
Cromileptes altivelis	Humpback grouper	Yes	Yes	Data deficient	Rimmer and Glamuzina, 2017
Hyporthodus septemfasciatus	Seven-band grouper	-	Yes	Data deficient	Rimmer and Glamuzina, 2017
Mycteroperca tigris	Tiger grouper	-	-	Data deficient	Shen et al., 2021

Table 1 (continued) .....continued on the next page

		Seedstock		
Hybrids	**Wild capture**	**Hatchery**	**Conservation Status**	**Reference**
Cephalopholis fulva x Paranthais furcifer	No	Research only	-	Ng et al., 2022
Cromileptes altivelis x E. fuscoguttatus	No	Yes	-	Rimmer and Glamuzina, 2017
Mycteroperca tigris x E. lanceolatus	No	Research only	-	Shen et al., 2021
E. amblycephalus x E. akaara	No	Research only	-	Rimmer and Glamuzina, 2017
E. coioides x E. fuscoguttatus	No	Yes	-	Rimmer and Glamuzina, 2017
E. coioides x E. lanceolatus	No	Yes	-	Sun et al., 2016
E. costae x E. marginatus	No	Research only	-	Rimmer and Glamuzina, 2017
E. fuscoguttatus x E. coeruleopunctatus	No	Yes	-	Rimmer and Glamuzina, 2017
E. fuscoguttatus x E. lanceolatus	No	Yes	-	Rimmer and Glamuzina, 2017
E. fuscoguttatus x E. polyphekadion	No	Yes	-	Rimmer and Glamuzina, 2017
E. lanceolatus x E. polyphekadion	No	Yes	-	Rimmer and Glamuzina, 2017
E. lanceolatus x C. altivelis	No	Yes	-	Rimmer and Glamuzina, 2017
E. marginatus x E. aenues	No	Research only	-	Rimmer and Glamuzina, 2017
E. morio x Centropristis striata	No	Research only	-	Rimmer and Glamuzina, 2017
E. tukula x E. lanceolatus	No	Yes	-	Rimmer and Glamuzina, 2017
E. bruneus x E. lanceolatus	No	Research only	-	Park et al., 2018

closed fishing seasons have been observed to positively impact the recovery of fish populations (Macusi et al., 2022). This has been documented in various studies and research papers. The closure of fishing seasons is a management strategy that aims to regulate fishing activities and prevent overfishing (Dunn et al., 2011). By prohibiting fishing during certain periods of the year, fish populations can reproduce and replenish their numbers (Hixon et al., 2014). This, in turn, leads to an increase in the overall grouper population and a healthier ecosystem. Therefore, closed fishing seasons may be an effective tool in promoting sustainable fishing practices and ensuring the long-term viability of grouper populations. Limited research has been conducted regarding the implementation of closed fishing seasons specifically targeting reef fisheries, compared to studies focusing on pelagic fish resources. A study was conducted in Belize, a country that has emerged as a pioneer in conserving the Nassau grouper. The conservation efforts primarily revolve around implementing closed fishing seasons at sites where the species form spawning aggregations. The impact of seasonal closures becomes apparent when examining the size distributions of sites subject to exploitation versus those not (Tewfik et al., 2017). According to the National Oceanic and Atmospheric Administration (NOAA) Fisheries, it has been determined that in the South Atlantic region, the commercial and recreational fishing seasons are officially closed from January to April. This temporary closure has been implemented to safeguard the red grouper species during their crucial peak spawning period. By imposing this measure, it is anticipated that the red grouper population will be afforded the necessary protection and support for successful reproduction and overall sustainability. The same applies to all shallow-water grouper during their spawning season (https://www.fisheries.noaa.gov/).

The non-consumptive utilization of groupers, particularly through eco-tourism (Shideler and Pierce, 2016), has been identified as a potential strategy to positively impact the population of this

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species in the wild. This approach is based on the premise that groupers are highly valued by recreational divers and snorkelers, who are willing to pay for the opportunity to observe these fish in their natural habitat. By providing an alternative source of income for local communities that is not dependent on the extraction of groupers for food or trade, eco-tourism may help to reduce fishing pressure on wild populations (Fabinyi, 2020). Furthermore, the increased awareness and appreciation of groupers that can result from eco-tourism activities may also lead to greater conservation efforts and improved management of these species. Overall, the non-consumptive utilization of groupers through eco-tourism represents a promising avenue for promoting the sustainable use and conservation of these important marine resources.

Limited information is available on the current state of global trade dynamics of grouper fish despite its considerable demand in local and global markets. Based on the comprehensive global capture fisheries dataset provided by the Food and Agriculture Organization (FAO), the top ten countries that have emerged as prominent producers of grouper include Indonesia, China, Philippines, Mexico, Malaysia, Brazil, Pakistan, Nigeria, United Arab Emirates, and United States. The FAO's dataset serves as a valuable resource for understanding the global landscape of grouper production, shedding light on the relative contributions of these nations to the overall output of these economically important fish species. These countries account for over 83% of the total landings from 2010 to 2015 (Amorim et al., 2019). Over 20 countries, including grouper, facilitate the live reef food fish trade (LRFFT) to Hong Kong. Hong Kong serves as the central international trade hub for this industry. The LRFFT is indirectly distributed to Mainland China through Hong Kong (Khasanah et al., 2020). The demand for grouper fish is substantial across multiple fishing industry sectors, encompassing commercial, recreational, and subsistence fishers (Frisch et al., 2016). According to a study conducted by Khasanah et al. (2020), it has been observed that grouper fish tend to command the highest prices among the available seafood options in local markets. The LRFFT is primarily motivated by the desire to meet the demand for food consumption (Fabinyi, 2016) and the aquarium trade (Madeira and Calado, 2019). The grouper, a highly sought-after fishery commodity in Southeast Asia, is prominent in the region's fishing industry (Rimmer and Glamuzina, 2017). However, it has attracted considerable attention due to its involvement in the LRFFT, which has subjected it to extensive exploitation (Burgess et al., 2020). The steep prices offered by exporters to local fishermen have resulted in a situation where the targeted species are at risk of being excessively depleted due to overfishing.

The NOAA Fisheries have expressed a strong dedication towards safeguarding and rehabilitating the populations of *E. striatus*, the most threatened species of grouper (Asch and Erisman, 2018). The conservation and management of endangered species is of utmost importance. To this end, improving the accuracy of the fisheries landing data on grouper and establishing additional marine protected areas, such as No-take marine reserves, is deemed necessary. The implementation of a no-take marine reserve marine protected area (MPA) has been proposed as a potential solution to address the overfishing of grouper (Andrello et al., 2013; Friedlander et al., 2017). This approach involves the establishment of a designated area within the marine environment where all forms of fishing and other extractive activities are prohibited. By doing so, the MPA's marine ecosystem can recover and replenish its fish stocks, which can then spill over into adjacent areas outside the MPA. This strategy has been shown to be effective in restoring depleted fish populations and improving the marine environment's overall health (Frisch et al., 2016). Establishing MPAs has been recognized as a potential mechanism to enhance larval dispersal between neighboring MPAs, which can have significant implications for fisheries

productivity (Cabral et al., 2020). The empirical evidence suggests that implementing a network of MPAs in the Gulf of California has increased the abundance of commercially important species in adjacent fished areas (Ramírez-Ortiz et al., 2022). Population connectivity holds great significance in the context of regional-scale resilience against anthropogenic disturbances (Lequeux et al., 2018). It is widely recognized as a crucial criterion in the planning and establishing MPAs. Larval dispersal is a fundamental mechanism that plays a significant role in facilitating population connectivity. MPAs have emerged as a prominent strategy for safeguarding marine ecosystems and promoting population connectivity. Therefore, establishing a no-take marine reserve MPA represents a promising approach to address the issue of overfishing.

China

China is the leading global producer of grouper, accounting for 65% of the world's production (Figure 1). Grouper aquaculture has been practiced for 50 years in China (Xiao et al., 2019). China is home to eleven prevalent cultured species of grouper, including but not limited to *E. tauvina, E. lanceolatus, E. malabaricus, E. areolatus, and E. bleekeri* (Rimmer and Glamuzina, 2017). The prevalent methods of grouper aquaculture in this area encompass the utilization of floating cages and inland ponds (Kang et al., 2018). Recently, there has been an increase in the utilization of High-density polyethylene (HDPE) circular cages, which can accommodate a larger number of fish (Megarajan et al., 2022a). The HDPE cages are utilized within the regions of Hainan Province and Hongkong (Pang et al., 2023). In this region, groupers are commonly fed with moist pellets and trash fish as a source of sustenance (Mo et al., 2018).

One of the challenges faced in grouper aquaculture practice is water pollution, which may arise from various sources such as chemical pollutants, plastic waste, heavy metals, and toxic substances (Li and Achal, 2020). Maintaining good water quality in aquaculture operations is often complicated by various factors, including the accumulation of trash fish at the bottom of cages, algal blooms, and poor water flow (Xie et al., 2021b). These problems may significantly affect the overall success of grouper farms. The seasonal variation in water temperature has a considerable impact on floating cage operations. During colder seasons, floating cages are not recommended due to the potential for high mortality rates among grouper caused by the cold water (Sun et al., 2019). One additional issue pertains to the differential growth of grouper, which results in instances of cannibalism (Yang et al., 2021). The disease and high mortality rates during the juvenile stage are prevalent in grouper farming (Shen et al., 2017). China has made significant progress in grouper aquaculture, particularly in the establishment of additional hatcheries and nurseries (Zhou et al., 2019). The utilization of large circular cages made from HDPE has proven to be a viable solution to meet the growing demand in both domestic and international markets (Megarajan et al., 2022a). Efficient moist pellets have been developed and utilized to promote optimal growth and production of grouper (Mo et al., 2016).

Taiwan

Taiwan accounts for 17% of global production and is the second-largest producer of grouper worldwide (Figure 1). Taiwan has successfully cultivated over 40 marine fish species for mariculture (Lu et al., 2015). During the 1970s and 1980s, *E. coioides, E. lanceolatus, Trachinotus blochii, Lutjanus argentimaculatus, L. stellatus,* and *Acanthopagrus latus* were seen to undergo full-cycle grouper aquaculture in large volumes and are still in use today (Kuo et al., 2016). There are 15 species of grouper that are commonly cultured, with the most prevalent species being *E. lanceolatus, E. coioides, E.* malabaricus, and E. fuscoguttatus (Lee et al., 2021). Annually, 20 million fries and over 7000 t of grouper are produced from

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700 hectares, comprising 2001 hatchery and grow-out farms (Guy et al., 2014). They supply fertilized eggs and seed grouper to export markets (Rimmer and Glamuzina, 2017). The cultivation of fish can be carried out through two methods, namely indoor and outdoor techniques, which include floating cages and ponds (Cherrie et al., 2020). The predominant feeding practice among grouper farmers involves the utilization of moist pellets (Rimmer et al., 2017). They are a significant producer of grouper that meets marketable size standards (Megarajan et al., 2022b). They are one of the leading producers of fingerlings in Asia (Rimmer and Glamuzina, 2017). In South Taiwan, family-run outdoor pond farms were common for raising grouper (Rimmer and Glamuzina, 2017; Megarajan et al., 2022a).

The escalating issue in Taiwan pertains to water quality and its correlation with diseases (Chen et al., 2022). The deterioration of water quality is associated with an increase in mortality and incidence of diseases. The most prevalent disease among groupers is viral nervous necrosis, which researchers have suggested may be transmitted to the fish by ingesting infected copepods, a common food source for juvenile groupers (Huang et al., 2017). The issue of cannibalism (Kuo et al., 2021) and bird predation (Wang et al., 2020) also pose a challenge in grouper farming. Taiwan has made significant advancements in grouper aquaculture, focusing on specialized areas such as brood stock, hatchery, nursery, and grow-out (Ting et al., 2015). The successful mass production of fertilized eggs for grouper has been achieved (Noh et al., 2019). The development of fry production systems and the implementation of specialized subsystems (Fachry et al., 2018) and division of labor have been major developments for grouper farmers (Lee et al., 2022). Their efficiency in producing live feeds, particularly to feed juvenile grouper with rotifer and copepods, is exceptionally good (Rayner et al., 2015). Formulated feeds have become prevalent in the aquaculture industry to promote the optimal growth of grouper species (Glamuzina and Rimmer, 2022). The hatchery for grouper is operated by individuals with extensive experience in the field (Rimmer and Glamuzina, 2017). The government supported extensive research and development initiatives and established an extensive infrastructure to support the cultivation and processing of grouper (Lin et al., 2023). Significant government support and well-structured industry organization for grouper are critical for the long-term success of grouper farming. The Economic Cooperation Agreement (EFCA) signed in 2010 between China and Taiwan, a trade agreement, has facilitated favorable market operations for grouper in Taiwan (Lo, 2022).

Indonesia

Indonesia accounts for 11% of the worldwide production of grouper, making it the third-largest producer of this fish (Figure 1). The expansion of grouper aquaculture has been observed in various regions of Indonesia (Henriksson et al., 2017). However, there is a lack of statistical information on the quantity of grouper aquaculture operations in this country. The farming techniques used in this area include full-cycle aquaculture and wild-caught grow-out (Fachry et al., 2018). Cromileptes altivelis is an example of a wild-caught grow-out species of grouper that is highly valued in the market due to its high cost (Khasanah et al., 2020). The Full-cycle culture involves the significant production of *E. fuscoguttatus* species (Fachry et al., 2018). The Asia-Pacific region relies heavily on Indonesia as the primary source of fingerlings (Ismi and Budi, 2020). Grouper farms use floating cages and ponds for their operations (Mayerle et al., 2018). Furthermore, there are tanks utilized for nursery and hatchery purposes, particularly in East Java and Southern Sumatra (Rimmer and Glamuzina, 2017). Grouper are commonly fed with trash fish and pellets as a sustenance (Rimmer and Glamuzina, 2019). The broodstock of E. fuscoguttatus demonstrates consistent spawning activity throughout the year (Fatma et al., 2022). Currently, two hybrid species, namely *E.*

fuscoguttatus x E. lanceolatus, are being cultured in Indonesia (Muzaki et al., 2021). These two hybrid varieties exhibit greater disease resistance and have a shorter maturation period of 9 to 12 months, attributed to their rapid growth rate. High-value grouper species, such as *Cromileptes* and *Plectropomus*, are frequently transported by air, whereas less expensive grouper species are commonly transported by land and water vehicles (Rimmer and Glamuzina, 2017).

One prevailing concern in Indonesia is the reduced survival rate of juvenile grouper, which can be attributed to cannibalistic behaviors (Novriadi, 2019). The challenge associated with expanding grouper aquaculture pertains to identifying the most suitable spots for additional grouper farms that offer good water quality conditions conducive to growth and development (Yanuhar et al., 2022). Too many grouper seeds are available due to hatcheries leads to the capacity of grow-out farms being exceeded, which results in a high mortality rate for grouper seedstock and the price of grouper seed falls due to oversupply (Rimmer and Glamuzina, 2017). The challenges faced in Indonesia concerning grouper aquaculture include the substantial initial investment cost and limited availability of funds and credit for initiating the business (Khasanah et al., 2020). The lack of technical skills among small-scale grouper culturists is also perceived as a problem (Herry et al., 2019). Several species, including *E. coioides, E. fuscoguttatus*, and *C. altivelus* have been successfully spawned as broodstock for the advancement of grouper farming in this region (Rimmer and Glamuzina, 2017). The Indonesian Government, in partnership with the Ministry of Marine Affairs and Fisheries (MMAF) Institute for Marine Research and Development in Gondol, has provided significant support to the initiative aimed at achieving sustainable grouper aquaculture (Khasanah et al., 2020). This collaboration involves the participation of Japanese and Australian countries.

Malaysia

Malaysia has 719 cage fish farmers, with 37% involved in the grouper industry (Iliyasu et al., 2015; Islam et al., 2016). Seedstocks are obtained from the wild for grow-out aquaculture (Waludin et 2018). Both private and government hatcheries are present with the intent of growing grouper (Cheng et al., 2015). Most of the seedstock for grouper, specifically E. lanceolatus, E. fuscoguttatus, and C. altivelis species, are sourced from Taiwan (Ching et al., 2018). The utilization of net cages in grouper farming is prevalent in the regions of Sabah and Sarawak (Arai, 2015). The predominant species cultured in the eastern and peninsular regions of Malaysia are *E. coioides, E. tauvina, E. fuscoguttatus, E. lanceolatus, P. leopardus,* and *C. altivelis* (Rimmer and Glamuzina, 2017). Grouper are fed with low-value fish species commonly referred to as “trash fish” (Islam et al., 2016).

The hatchlings exhibit a low level of resilience and a high mortality rate during their initial developmental stages (Ariff et al., 2019). Fry and fingerlings exhibit higher mortality rates and are susceptible to various diseases. Despite the presence of government and private hatcheries, the insufficient number of grouper hatcheries remains an important challenge to the successful aquaculture of this species in the region (Islam et al., 2016). The declining accessibility of trash fish is attributed to anthropogenic threats and overfishing (Jagerroos, 2016). The survival rate of *E. lanceolatus* and *C. altivelis* is adversely affected by water quality issues (Rimmer and Glamuzina, 2017). Improved health in the broodstock is also a necessity in this region (Hassan et al., 2015). There is an inadequate number of male grouper spawners, resulting in inconsistent and unpredictable spawning patterns. Grouper has few spawns, poor fertilization and hatchery rates, weak hatchlings, and a high death rate in the early stages (Rimmer and Glamuzina, 2017). It has been

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determined that E. fuscoguttatus exhibits a favorable survival rate within the waters of Malaysia (Fui et al., 2016). The Department of Fisheries (DoF) of Malaysia (Fathi et al., 2018) and Universiti Putra Malaysia (UPM) (Alipiah et al., 2016) conduct research and produces grouper larvae for aquaculturists, private hatcheries, and nursing constitutes a significant development in this region. Additionally, UPM offers training on the cultivation of grouper. The government has designated areas for aquaculture and has built infrastructure for it (Jumatli and Ismail, 2021).

Philippines

The grouper aquaculture industry in the Philippines depends on the grow-out of fry and fingerlings captured from the wild (Palma et al., 2019). The Philippines is a major supplier of wild-caught grouper fry, fingerlings, and sub-adult in Southeast Asian region (Rimmer & Glamuzina, 2017). The sources of grouper are found in various regions of the Philippines, including Pangasinan, Cavite, Mindoro, Quezon, Masbate, Bulacan, Cagayan, Dadiangas, Zamboanga del Sur, and Negros Oriental (Pomeroy et al., 2007; Alcantara and Yambot, 2016). When the seedstock for grouper aquaculture is insufficient, the Philippines imports grouper from Taiwan (Fachry et al., 2018) and Indonesia (Khasanah et al., 2020). Currently, an increasing number of individuals are engaged in grouper farming, particularly in Palawan (Villanueva et al., 2021). The practice of cultivating groupers involves the utilization of floating net cages, fixed net cages, or ponds that have been previously employed for shrimp aquaculture (Rimmer and Glamuzina, 2017). There are limited broodstock operations and multiple privately-owned hatcheries (Alcantara and Yambot, 2016). The popular cultured species include *E. coioides, E. malabaricus, E. lanceolatus, E. fuscoguttatus*, with a relatively minor production of *P. leopardus* and C. altivelis (Alcantara and Yambot, 2016; Villanueva et al., 2021). Groupers are sold at the local markets, hotels, and restaurants in Manila (Peralta-Milan et al., 2020).

The Philippines faces a shortage of fry and fingerlings of suitable size for the grow-out of grouper, which presents a significant challenge (Cruz-Lacierda and Nagasawa, 2017). The poor quality of fry and fingerlings can be attributed to using destructive capture methods such as mangrove nets and lift nets (Marte and Toledo, 2015). The issues of trash fish supply, overfishing, and destructive fishing practices pose a concern in grouper resources (Rimmer and Glamuzina, 2017). The large amount of fry and fingerlings exported to neighboring Asian countries now becomes a problem in the Philippines due to the groupers' population decline, which may be attributed to this activity (Cabasan et al., 2020). Challenges encountered in grouper aquaculture include grow-out disease caused by *Vibrio* spp. (Nurliyana et al., 2019), poor water quality (Palanca-Tan, 2018), and damage to cages from storms (Monteclaro et al., 2018). Problems in spawning and post-hatch low survival due to parasites and diseases are among the problem in the grouper industry in this country (Rimmer and Glamuzina, 2017). Despite significant research in hatchery techniques, grouper aquaculture continues to depend on wild seedstock (Palma et al., 2019). Grouper aquaculture is costly for small-scale fish farmers (Rimmer and Glamuzina, 2017). The Southeast Asian Fisheries Development Center-Aquaculture (SEAFDEC), located in Tigbauan, Ilo-ilo (Mamauag and Ragaza, 2017), is engaged in the provision of technical expertise and research activities of grouper species such as *E. coioides and E. malabaricus*. SEAFDEC has researched broodstock development, seed production, and nursery and grow-out culture. Hatchery facilities for E. fuscoguttatus have been developed in Palawan to allow the production of fry and fingerlings (Villanueva et al., 2021).

Thailand

Grouper aquaculture is rapidly

growing in Thailand (Dennis et al., 2020). Floating net cages are utilized in the provinces of southern and eastern Thailand (Rimmer et al., 2017). There has been a transition observed among farmers from aquaculture of shrimp to grouper farming (Rimmer and Glamuzina, 2017). Important farmed grouper are *E. lanceolatus* and *E. fuscoguttatus*. They are also one of Southeast Asia's main sources of wild-caught grouper seedstock (Rimmer and Glamuzina, 2017). There exist private and government hatcheries for grouper.

A grouper hatchery is available for species like *E. lanceolatus* and *E. fuscoguttatus.* Wild-caught juvenile grouper species like *E. coioides, E. malabaricus,* and *E. bleekeri* are used for grow-out aquaculture (Fachry et al., 2018). They either sell grouper on the domestic market or export it to Hongkong, Singapore, and Malaysia (Rimmer and Glamuzina, 2017). In Thailand, there are problems with grouper, such as the high number of viral diseases and parasites that affect this species (Jungi et al., 2022). One of the primary concerns in this locality involves the lack of accessibility to both trash fish and expensive synthetic feed (Rimmer et al., 2017). There have been instances of theft, which is why grouper cages have been placed in front of the home of owners (Rimmer and Glamuzina, 2017). Raising groupers has emerged as a key area of focus for the government. Department of Fisheries, Ministry of Agriculture and Cooperatives research and development efforts aimed at enhancing grouper production (Sutthinon et al., 2014).

Vietnam

Grouper aquaculture is a recently established enterprise in Vietnam (Nankervis et al., 2022). There is a growing trend towards cultivating groupers in aquaculture (Dennis et al., 2020). Grouper aquaculture relies on the grow-out of wild-caught fry and fingerlings (Palma et al., 2019). Many operations are conducted on a small scale, such as family-operated grouper aquaculture (Chi et al., 2017). The prevalent cultured species include *E. coioides, E. malabaricus,* and *E. bleekeri* (Van Truong et al., 2016). The grouper industry employs various cultivation methods, including floating net cages, fixed net cages, and ponds used for shrimp culture (Rimmer and Glamuzina, 2017). Locally, fish caught from nearby waters are used as trash fish to feed the grouper (Van Truong et al., 2017). Grouper aquaculture is abundant in the Northern Province and South-central Provinces of Vietnam (Rimmer and Glamuzina, 2017). Hybrids are also employed in aquaculture, such as the hybrid of *E. fuscoguttatus* x *E. lanceolatus* and *E. fuscoguttatus* x *C. altivelis* (Nankervis et al., 2022; Dennis et al., 2020). In the North Province of Vietnam, there is a notable production of large-sized grouper intended for export to China. On the other hand, the South-central Province is known for cultivating small-sized grouper mostly for local consumption (Rimmer and Glamuzina, 2017).

The primary issues in grouper aquaculture include the supply of grouper seed and its poor quality, which can be attributed to the practices involved in catching and handling (Rimmer and Glamuzina, 2017). The cost of trash fish is relatively high (Dennis et al., 2020). Currently, the government is undertaking research on grouper through the Research Institute for Aquaculture-1 (RIA-1) (Dennis et al., 2020) and Fisheries University in Nha Trang (Turon et al., 2020). The focus of these research institutions is on DNA metabarcoding, hatchery techniques, and broodstock maintenance for grouper (Rimmer et al., 2017).

Other Asian countries

Cambodia is a minor contributor to the global production of grouper, having produced 200 tonnes of this fish in 2014 (Bueno, 2018). Marine cage farms typically consist of 20 to 50 cages, with approximately two-thirds of the cages being utilized for seabass cultivation and the remaining one-third being allocated for grouper

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cultivation (Joffre and Chheng, 2016). There are no public or private hatcheries, so they must import fingerlings from other Asian countries or gather them from the wild (Rimmer and Glamuzina, 2017). Groupers are fed with trash fish (Sorphea et al., 2018).

Cultivating groupers in net cages commercially is observed in Kyun Su Township, located in the Taninthayi Division of Myanmar (Schneider et al., 2015). Myanmar's grouper production 2014 was recorded at 150 tonnes, indicating a relatively small contribution to the global output of this fish species (Rimmer and Glamuzina, 2017). This region has no grouper hatchery facilities (Aung, 2021). They rely on the grow-out of wild-captured *E. coioides* and *E. tauvina.* Since groupers (*Epinephelus* spp.) are common and easy to capture, local populations have not traditionally been interested in them (Rimmer and Glamuzina, 2017). Groupers have recently gained popularity in the fisheries trade because of high foreign market demand, inspiring farmers to start testing their aquaculture.

India is a significant contributor to the global fish farming industry, primarily focusing on inland finfish aquaculture (Rutaisire et al., 2017). However, the potential for mariculture production in the country remains largely unexplored. India invests more in freshwater and brackish water fish aquaculture ponds (Ninawe et al., 2017). The Ministry of Commerce and Industries, Marine Products Export Development Authority, and Ministry of Agriculture Indian Council of Agriculture Research (ICAR) have provided support for grouper aquaculture, which is being carried out in collaboration with the Central Marine Fisheries Research Institute (CMFRI) (Pathak et al., 2022). Despite the standardization of methods for broodstock development, sex inversion, and captive spawning of certain species of grouper, such as *E. tauvina, E. malabaricus, E. merra,* and *E. coioides*, by CMFRI, the application of these techniques has been limited to laboratory settings (Ranjan et al., 2022b). This is due to challenges in obtaining natural males from the wild, issues with sex reversal, and troubles in larval rearing, which are attributed to the small mouth size of the species. As a result, the dissemination of these methods to farmers has been hindered. Despite the fish's high prices on the international market, these issues discouraged Indian farmers from pursuing grouper farming.

Culturing marine finfish in floating cages has emerged as a still developing industry in Brunei Darussalam (Azmey et al., 2020). The most common cultivated species include *E. coioides, E. suillus, E. malabaricus,* and *E. bleekeri* (Tamat et al., 2019). Fingerlings were found to be vulnerable to bacterial, fungal, and parasitic infestation due to the stress they experienced during transportation from various Asian countries (Azmey et al., 2020). A designated area for aquaculture has been established, with a limited number of permitted farms, and obtaining a license is a mandatory requirement for those engaging in grouper aquaculture (Bueno, 2018). The groupers within this region are provided sustenance through the utilization of trash fish (Eu et al., 2022).

The annual aquaculture production in Singapore is extremely low (Shen et al., 2021). Most of the fish produced in Singapore is sold on the local market. From 1965 to 1980, the primary focus of aquaculture was on cultivating freshwater fish species. The main varieties of freshwater species cultivated are tilapia spp and various strains of common carp (Lim, 2016). Due to the limited space available for freshwater aquaculture, aquaculture has shifted from freshwater culture to marine culture (Shen et al., 2021). Seabass, cultivated in Singapore for more than 40 years, is the main species for marine aquaculture (Liu et 2022). *Epinephelus* spp and a hybrid of *Mycteroperca tigris* × *Epinephelus lanceolatus* have been subjected to aquaculture. However, their marine aquaculture production remains low (Shen et al., 2021).

CONCLUSION

Asia is home to a total of 48 species and 16 hybrids of grouper that are currently being farmed. The aquaculture industry in China and Taiwan has experienced a notable surge in the production of grouper. The current review paper also includes information on the conservation status of farmed grouper species, with 67% rated as least concern, 17% as data deficient, 10% as vulnerable, and 2% each for critically endangered (*E. striatus*), endangered (*E. akaara*), and near threatened (*E. aeneus*). The declining wild grouper population, notably in Asia, severely impacts the conservation status of the species. This decline demonstrates the tremendous global threats that groupers receive. These threats include overfishing, water pollution, and capture-based aquaculture. Various strategies have been proposed for managing grouper resources to augment their population in the wild. These strategies include refraining from fishing during spawning aggregation, implementing a close season, establishing marine protected areas (MPAs), implementing a non-consumptive strategy (eco-tourism), and promoting additional full-cycle grouper aquaculture.

The current paper highlights four primary concerns on grouper aquaculture in Asia. Firstly, the absence of hatcheries in most Asian countries has led to a heavy reliance on wild-caught juvenile grouper, thereby contributing to a decline in the population of this species in its natural habitat. Secondly, the poor quality of seedstock, characterized by low survival rates during early stages and broodstock quality, has emerged as a significant challenge in this field of study. Third, providing financial and technical support is crucial in the progress of grouper aquaculture. Fourth, the expensive nature of trash fish as a food source for grouper, coupled with the limited availability of fish pellets in several Asian nations, presents a challenge.

On the other hand, there has been notable advancement in some Asian region about grouper aquaculture. Specifically, there has been a surge in research-based initiatives facilitated by research institutions from both the private and public sectors and academic institutions. Additionally, there has been an increase in government support in terms of financial and technical assistance. Finally, it has been observed that the success of grouper aquaculture is contingent upon establishing well-organized aquaculture organizations.

REFERENCES

Afero, F., Miao, S., & Perez, A. A. (2010). Economic analysis of tiger grouper Epinephelus fuscoguttatus and humpback grouper Cromileptes altivelis commercial cage culture in Indonesia. *Aquaculture international*, 18, 725-739.

Alcantara, S. G., & Yambot, A. V. (2016). DNA barcoding of commercially important grouper species (Perciformes, Serranidae) in the Philippines. *Mitochondrial DNA Part A*, 27(6), 3837-3845.

Alipiah, N. M., Ramli, N. H. S., Low, C. F., Shamsudin, M. N., & Yusoff, F. M. (2016). Protective effects of sea cucumber surface-associated bacteria against Vibrio harveyi in brown-marbled grouper fingerlings. *Aquaculture Environment Interactions*, 8, 147-155.

Amagai, T., Murata, R., & Soyano, K. (2020). Spawning characteristics of a lunar-synchronized spawner, the honeycomb grouper Epinephelus merra, under artificial conditions. *Aquaculture Science*, 68(3), 235-242.

Amorim, P., Sousa, P., Jardim, E., & Menezes, G. M. (2019). Sustainability status of data-limited fisheries: global challenges for snapper and grouper. *Frontiers in Marine Science*, 6, 654.

Andrello, M., Mouillot, D., Beuvier, J., Albouy, C., Thuiller, W., & Manel, S. (2013). Low connectivity between Mediterranean marine protected areas: a biophysical modeling approach for the dusky

 DOI: https://doi.org/10.59120/drj.v14i2.109

grouper Epinephelus marginatus. *PLoS One*, 8(7), e68564.

Arai, T. (2015). Diversity and conservation of coral reef fishes in the Malaysian South China Sea. *Reviews in Fish Biology and Fisheries*, 25, 85-101.

Aride, P. H. R., Gomes, M. F. S., Azevedo, D. G., Sangali, G. R., Silva, A. C. F., Lavander, H. D., & Faggio, C. (2021). Dusky grouper Epinephelus marginatus growth and survival when exposed to different photoperiods. *Fishes*, 6(3), 31.

Ariff, N., Abdullah, A., Azmai, M. N. A., Musa, N., & Zainathan, S. C. (2019). Risk factors associated with viral nervous necrosis in hybrid groupers in Malaysia and the high similarity of its causative agent nervous necrosis virus to reassortant red-spotted grouper nervous necrosis virus/striped jack nervous necrosis virus strains. *Veterinary World,* 12(8), 1273.

Arlinghaus, R., Abbott, J. K., Fenichel, E. P., Carpenter, S. R., Hunt, L. M., Alós, J., & Manfredo, M. J. (2019). Governing the recreational dimension of global fisheries. *Proceedings of the National Academy of Sciences*, 116(12), 5209-5213.

Asch, R. G., & Erisman, B. (2018). Spawning aggregations act as a bottleneck influencing climate change impacts on a critically endangered reef fish. *Diversity and Distributions*, 24(12), 1712-1728.

Aung, O. (2021). Sustainable aquaculture and resource enhancement in Myanmar. In Proceedings of the International Workshop on the Promotion of Sustainable Aquaculture, Aquatic Animal Health, and Resource Enhancement in Southeast Asia. Aquaculture Department, Southeast Asian Fisheries Development Center. 41-45.

Azmey, S., Taruna, M., Taha, H., & Arai, T. (2020). Prevalence and infestation intensity of a piscicolid leech, Zeylanicobdella arugamensis on cultured hybrid grouper in Brunei Darussalam. Veterinary Parasitology: Regional Studies and Reports, 20, 100398.

Bahri, S., & Jata, M. E. (2021). System Analysis and Marketing Strategy Grouper (Ephinephelus SPP) by Fishermen at Base Fish Landing (PPI) Oeba, Lama City District Kupang City. *International Journal of Multidisciplinary Research and Analysis*, 4(8), 1193-1199.

Basith, A., Abinawanto, Kusrini, E., & Yasman. (2021). Species inventories and conservation status of groupers (family Serranidae) from Madura Island, East Java, Indonesia. *In AIP Conference Proceedings* (Vol. 2331, No. 1, p. 050021). AIP Publishing LLC.

Bueno, P. B. (2018). Capacities for Managing the Development of ASEAN Aquaculture. Fish for the People, 16(3), 10-18.

Bunlipatanon, P., & U-taynapun, K. (2017). Growth performance and disease resistance against V ibrio vulnificus infection of novel hybrid grouper (*E pinephelus lanceolatus* × *E pinephelus fuscoguttatus*). *Aquaculture Research,* 48(4), 1711-1723.

Burgess, A. I., Callan, C. K., Touse, R., & Delos Santos, M. (2020). Increasing survival and growth in larval leopard coral grouper (*Plectropomus leopardus)* using intensively cultured Parvocalanus crassirostris nauplii. *Journal of the World Aquaculture Society*, 51(1), 171-182.

Cabasan, J. P., Arceo, H. O., Pata, P., Labrador, K. L., Casauay, R. B., Miller, N., & Baria-Rodriguez, M. V. (2021). Combining information on otolith morphometrics and larval connectivity models to infer stock structure of *Plectropomus leopardus* in the Philippines. *Marine Ecology Progress Series*, 679, 115-131.

Cabral, R. B., Bradley, D., Mayorga, J., Goodell, W., Friedlander, A. M., Sala, E., & Gaines, S. D. (2020). A global network of marine protected areas for food. *Proceedings of the National Academy of Sciences,* 117(45), 28134-28139.

Chen, J. C., Chen, T. L., Wang, H. L., & Chang, P. C. (2022). Underwater abnormal classification system based on deep learning: A case study on aquaculture fish farm in Taiwan. *Aquacultural Engineering*, 99, 102290.

Chen, Y. Y., Cheng, A. C., Cheng, S. A., & Chen, J. C. (2018). Orange-spotted grouper Epinephelus coioides that have encountered low salinity stress have decreased cellular and humoral immune reactions and increased susceptibility to Vibrio alginolyticus. *Fish & shellfish immunology,* 80, 392-396.

Cheng, S. S., Senoo, S., Siddiquee, S., & Rodrigues, K. F. (2015). Genetic variation in the mitochondrial genome of the giant grouper *Epinephelus lanceolatus* (Bloch, 1790) and its application for the identification of broodstock. *Aquaculture Reports,* 2, 139-143.

Cherrie, B., Zipf, S., Knuckey, R., Lee, P., Borchert, T., & Nixon, D. (2020). Evaluation of two species, Cobia and Giant Grouper, as alternative species to farm in the WSSV affected areas of South East Queensland.

Chi, T. T. K., Clausen, J. H., Van, P. T., Tersbøl, B., & Dalsgaard, A. (2017). Use practices of antimicrobials and other compounds by shrimp and fish farmers in Northern Vietnam. *Aquaculture Reports,* 7, 40-47.

Ching, F. F., Othman, N., Anuar, A., Shapawi, R., & Senoo, S. (2018). Natural spawning, embryonic and larval development of F2 hybrid grouper, tiger grouper *Epinephelus fuscoguttatus* × *giant grouper E. lanceolatus. International Aquatic Research,* 10, 391-402.

Chuda, H., Ieda, K., Shirakashi, S., & Masuma, S. (2018). Differences in susceptibility to the skin fluke Benedenia epinepheli between Epinephelus bruneus, *E. septemfasciatus,* and a new hybrid grouper Kue-Tama, *E. bruneus* × *E. lanceolatus*. *Aquaculture*, 491, 346-350.

Cruz-Lacierda, E. R., & Nagasawa, K. (2017). Occurrence of praniza larvae of a gnathiid (Isopoda, Gnathiidae) on wild-caught orange-spotted grouper, *Epinephelus coioides* (Hamilton, 1822) (perciformes, serranidae), in lingayen gulf, Philippines. *Crustaceana*, 90(1), 101-110.

de Mitcheson, Y. J. S., Linardich, C., Barreiros, J. P., Ralph, G. M., Aguilar-Perera, A., Afonso, P., & Craig, M. T. (2020). Valuable but vulnerable: Over-fishing and under-management continue to threaten groupers so what now?. *Marine Policy,* 116, 103909.

De, M., Ghaffar, M. A., Bakar, Y., & Das, S. K. (2016). Effect of temperature and diet on growth and gastric emptying time of the hybrid, Epinephelus fuscoguttatus♀× E. lanceolatus♂. *Aquaculture Reports,* 4, 118-124.

Dennis, L. P., Ashford, G., Thai, T. Q., Van In, V., Ninh, N. H., & Elizur, A. (2020). Hybrid grouper in Vietnamese aquaculture: production approaches and profitability of a promising new crop. Aquaculture, 522, 735108.

Dunham, R. (2023). Aquaculture and fisheries biotechnology: genetic approaches. Cabi.

Dunn, D. C., Boustany, A. M., & Halpin, P. N. (2011). Spatio-temporal management of fisheries to reduce by-catch and increase fishing selectivity. *Fish and Fisheries,* 12(1), 110-119.

Efendi, D. S., Adrianto, L., Wardiatno, Y., & Agustina, S. (2020). The performance of stock indicators of grouper (*Serranidae*) and snapper (*Lutjanidae*) fisheries in Saleh Bay, Indonesia. *Aquaculture, Aquarium, Conservation & Legislation,* 13(5), 2431-2444.

Eu, A., Siok, C., & Biñas, J. B. (2022). Issues and challenges in sustainable development of fisheries and aquaculture of the Southeast Asian Region: Utilization of fishery resources. *The Southeast Asian State of Fisheries and Aquaculture* 2022, 113-117.

Evliyaoğlu, E., Eroldoğan, O. T., Yılmaz, H. A., Genç, M. A., Genç, E., Duncan, N., & Güroy, D. (2019). Artificial sex reversal of white grouper (*Epinephelus aeneus)* utilizing aromatase inhibitor (*Fadrozole*). *Aquaculture Research*, 50(5), 1539-1546.

Fabinyi, M. (2016). Producing for Chinese luxury seafood value chains: Different outcomes for producers in the Philippines and North America. *Marine Policy*, 63, 184-190.

Fabinyi, M. (2020). The role of land tenure in livelihood transitions from fishing to tourism. *Maritime Studies,* 19(1), 29-39.

Fachry, M. E., Sugama, K., & Rimmer, M. A.

(2018). The role of small-holder seed supply in commercial mariculture in South-east Asia. *Aquaculture*, 495, 912-918.

Fadli, N., Damora, A., Muchlisin, Z. A., Dewiyanti, I., Ramadhaniaty, M., Razi, N. M., Jamaluddin, J. A. F., Macusi, E. D., & Siti-Azizah, M. N. (2023). Phylogeographic Insights of Five Co-Habiting Grouper Species in The Indo-Malaya Archipelago. *HAYATI Journal of Biosciences*, 30(4), 743-756.

Fathi, S., Harun, A. N., Rambat, S., & Tukiran, N. A. (2018). Current issues in aquaculture: lessons from Malaysia. *Advanced Science Letters*, 24(1), 503-505.

Fatma, F., Mallawa, A., Najamuddin, N., Zainuddin, M., & Ayyub, F. R. (2022). Biological aspects of brown-marbled grouper (*Epinephelus fuscoguttatus*) from Taka Bonerate National Park, District of Selayar Islands, South Sulawesi, Indonesia. *Biodiversitas Journal of Biological Diversity*, 23(2).

Félix-Hackradt, F. C., Hackradt, C. W., & García-Charton, J. A. (2022). *Biology and Ecology of Groupers*. CRC Press.

Frable, B. W., Tucker, S. J., & Walker, H. J. (2019). A new species of grouper, *Epinephelus craigi* (Perciformes: Epinephelidae), from the South China Sea. *Ichthyological Research*, 66, 215-224.

Friedlander, A. M., Golbuu, Y., Ballesteros, E., Caselle, J. E., Gouezo, M., Olsudong, D., & Sala, E. (2017). Size, age, and habitat determine effectiveness of Palau's Marine Protected Areas. *PloS one*, 12(3), e0174787.

Frisch, A. J., Cameron, D. S., Pratchett, M. S., Williamson, D. H., Williams, A. J., Reynolds, A. D., & Hobbs, J. P. A. (2016). Key aspects of the biology, fisheries and management of Coral grouper. *Reviews in Fish Biology and Fisheries*, 26, 303-325.

Fui, C. F., Miura, A., Nakagawa, Y., Kato, K., Sakamoto, W., Takii, K., & Senoo, S. (2016). Aeration rate adjustment at night to prevent sinking syndrome-related death in the tiger grouper *E. pinephelus* fuscoguttatus (Perciformes: Serranidae) larvae. *Aquaculture Research*, 47(1), 165-175.

Glamuzina, B., & Rimmer, M. A. (2022). Grouper aquaculture world status and perspectives. *In Biology and Ecology of Groupers* (pp. 166-190). CRC Press.

Guy, J. A., McIlgorm, A., & Waterman, P. (2014). Aquaculture in regional Australia: responding to trade externalities. A Northern NSW case study. *Journal of Economic & Social Policy*, 16(1), 115-145.

Hassan, N. C., Aziz, A. H. A., Ali, N. M., Ariffin, N. A., Chu, I. K. C., Mustafa, S., & Sheriff, S. M. (2015). Genetic diversity in farmed tiger grouper broodstock inferred by Partial Cytochrome b Gene. *International Journal of Chemical, Environmental & Biological Sciences*, 3 (1), 2320-4087.

Heemstra, P. C., & Randall, J. E. (1993). Groupers of the world. F*AO Fisheries synopsis*, 16(125)

Henriksson, P. J. G., Tran, N., Mohan, C. V., Chan, C. Y., Rodriguez, U. P., Suri, S., & Phillips, M. J. (2017). Indonesian aquaculture futures–Evaluating environmental and socioeconomic potentials and limitations. *Journal of Cleaner Production*, 162, 1482-1490.

Herry, F. H., Muhammadar, A. A., Putra, D. F., & Irwan, Z. A. (2019). Feasibility study of grouper (Epinephelus sp) culture in Manyak Payed, Aceh Tamiang region, Indonesia. *In IOP Conference Series: Earth and Environmental Science* 348(1). IOP Publishing.

Hixon, M. A., Johnson, D. W., & Sogard, S. M. (2014). BOFFFFs: on the importance of conserving old-growth age structure in fishery populations. *ICES Journal of Marine Science*, 71(8), 2171-2185.

Huang, S. M., Cheng, J. H., Tu, C., Chen, T. I., Lin, C. T., & Chang, S. K. (2017). A bivalent inactivated vaccine of viral nervous necrosis virus and grouper iridovirus applied to grouper brood-fish (*Epinephelus coioides*) reduces the risk of vertical transmission. *Taiwan Veterinary Journal*, 43(03), 171-176.

Huang, W., Qin, Q., Yang, H., Li, S., Hu, C., Wang, Y., & Lin, H. (2016). Formation of diploid and triploid hybrid groupers (hybridization of *Epinephelus coioides*♀ × *Epinephelus lanceolatus*♂) and their 5S

gene analysis. *BMC genetics*, 17(1), 1-9.

Iliyasu, A., Mohamed, Z. A., & Hashim, M. (2015). Productivity growth, technical change and efficiency change of the Malaysian cage fish farming: an application of Malmquist Productivity Index approach. *Aquaculture International*, 23, 1013-1024.

Islam, G. M. N., Tai, S. Y., & Kusairi, M. N. (2016). A stochastic frontier analysis of technical efficiency of fish cage culture in Peninsular Malaysia. *SpringerPlus*, 5, 1-11.

Ismi, S., & Budi, D. S. (2020). Culture performance and economic profitability of cantang hybrid grouper (*Epinephelus fuscoguttatus fx epinephelus lanceolatus m*) fingerlings reared at different initial stocking sizes and nursery periods. *Indonesian Aquaculture Journal*, 15(1), 43-49.

Jagerroos, S. (2016). Assessment of living resources in the Straits of Malacca, Malaysia: case study. *J Aquac Mar Biol*, 4(1), 00070.

Jefri, E., ZAMANI, N. P., Subhan, B., & Madduppa, H. H. (2015). Molecular phylogeny inferred from mitochondrial DNA of the grouper *Epinephelus* spp. in Indonesia collected from local fish market. *Biodiversitas Journal of Biological Diversity*, 16(2).

Joffre, O., So, N., & Chheng, P. (2016). Aquaculture production in Cambodia: trends and patterns in recent years. *Inland Fisheries Research and Development Institute (Fisheries Administration) and WorldFish*. Phnom Penh, Cambodia, 1-26.

Jumatli, A., & Ismail, M. S. (2021). Promotion of sustainable aquaculture in Malaysia. *In Proceedings of the International Workshop on the Promotion of Sustainable Aquaculture, Aquatic Animal Health, and Resource Enhancement in Southeast Asia.* 31-40.

Jungi, S. V., Sangsuriya, P., Taengphu, S., Phiwsaiya, K., Sonthi, M., Nuangsaeng, B., & Dong, H. T. (2022). Detection of nervous necrosis virus RGNNV genotype in pearl gentian grouper (*Epinephelus lanceolatus*♂ × *E. fuscoguttatus*♀) fry imported to Thailand. *Aquaculture*, 561, 738659.

Kang, B., Liu, M., Huang, X. X., Li, J., Yan, Y. R., Han, C. C., & Chen, S. B. (2018). Fisheries in Chinese seas: What can we learn from controversial official fisheries statistics?. *Reviews in Fish Biology and Fisheries*, 28, 503-519.

Khasanah, M., Nurdin, N., Sadovy de Mitcheson, Y., & Jompa, J. (2020). Management of the grouper export trade in Indonesia. *Reviews in Fisheries Science & Aquaculture*, 28(1), 1-15.

Kim, Y. K., Lee, C. H., Lee, Y. D., & Han, S. H. (2019). Development of species-specific PCR for the identification of three grouper fish species (*Epinephelus septemfasciatus, E. bruneus* and *E. akaara*). *Indian Journal of Animal Research*, 53(4), 482-484.

Kobayashi, Y. (2022). Control of gonadal maturation and sex in grouper. *Aquaculture and Fisheries*.

Kuo, H. P., Chung, C. L., Hung, Y. F., Lai, Y. S., Chiou, P. P., Lu, M. W., & Kong, Z. L. (2016). Comparison of the responses of different recombinant fish type I interferons against betanodavirus infection in grouper. *Fish & shellfish immunology*, 49, 143-153.

Kuo, J., Chen, C. Y., Han, C. C., Ju, Y. M., & Tew, K. S. (2021). Analyses of diet preference of larval orange-spotted grouper (*Epinephelus coioides)* grown under inorganic fertilization method using next-generation sequencing. *Aquaculture*, 531, 735916.

Lafferty, K. D., Harvell, C. D., Conrad, J. M., Friedman, C. S., Kent, M. L., Kuris, A. M., & Saksida, S. M. (2015). Infectious diseases affect marine fisheries and aquaculture economics. *Annual review of marine science*, 7, 471-496.

Lee, H. C., Tseng, Y. L., Sung, W. Y., & Liu, W. H. (2022). Exploring the gender gap in marine affairs in Taiwan. *Marine Policy*, 137, 104937.

Lee, H. T., Liao, C. H., & Hsu, T. H. (2021). Environmental DNA (eDNA) Metabarcoding in the fish market and nearby seafood restaurants in Taiwan reveals the underestimation of fish species diversity in seafood. *Biology*, 10(11), 1132.

Lequeux, B. D., Ahumada-Sempoal, M. A., López-Pérez, A., & Reyes-Hernández, C. (2018). Coral connectivity between equatorial eastern Pacific marine protected areas: A biophysical modeling approach. *PloS one*, 13(8), e0202995.

Li, W., & Achal, V. (2020). Environmental and health impacts due to e-waste disposal in China–A review. *Science of the Total Environment*, 737, 139745.

Liang, Y., Xu, C., & Li, Q. (2023). Heterosis and genetic diversity of intraspecific hybrids crosses between two selected lines of the Pacific oyster Crassostrea gigas. *Aquaculture*, 569, 739369.

Liao, I. C., Su, H. M., & Chang, E. Y. (2001). Techniques in finfish larviculture in Taiwan. *Aquaculture*, 200(1-2), 1-31.

Lim, G. (2016). Value chain upgrading: Evidence from the Singaporean aquaculture industry. *Marine Policy*, 63, 191-197.

Lin, T. Y., Chen, C. L., Shih, Y. Y., Hsieh, H. H., Huang, W. J., Santschi, P. H., & Hung, C. C. (2023). A smallholders' mariculture device for rearing seafood: environmentally friendly and providing improved quality. *Sustainability*, 15(1), 862.

Liu, P., Xia, J. H., Sun, F., Wang, L., Yang, Z., Lee, M., & Yue, G. H. (2022). Breeding Asian seabass to increase survival against big belly disease and growth. *Aquaculture and Fisheries*.

Lo, L. C. (2022). Facilitating the Market with a Gift: The Politics of the ECFA between China and Taiwan (2008–2016). *Asian Studies Review*, 1-18.

Loh, J. Y., Chan, H. K., Yam, H. C., In, L. L. A., & Lim, C. S. Y. (2020). An overview of the immunomodulatory effects exerted by probiotics and prebiotics in grouper fish. *Aquaculture International*, 28, 729-750.

Longo, S. B., Clark, B., York, R., & Jorgenson, A. K. (2019). Aquaculture and the displacement of fisheries captures. *Conservation Biology*, 33(4), 832-841.

Lu, J. K., Chou, H. Y., Gong, H. Y., P Chiou, P., Huang, C. W., Chen, L. L., & Wu, J. L. (2015). The Marine aquaculture biotechnology status and its sustainability in Taiwan. *Current Biotechnology*, 4(3), 311-318.

Luiz, O. J., Woods, R. M., Madin, E. M., & Madin, J. S. (2016). Predicting IUCN extinction risk categories for the world's data deficient groupers (Teleostei: Epinephelidae). *Conservation Letters*, 9(5), 342-350.

Lupatsch, I., & Kissil, G. W. (2005). Feed formulations based on energy and protein demands in white grouper (*Epinephelus aeneus*). *Aquaculture*, 248(1-4), 83-95.

Ma, K. Y., & Craig, M. T. (2018). An inconvenient monophyly: an update on the taxonomy of the groupers (*Epinephelidae*). *Copeia*, 106(3), 443-456.

Macusi, E. D., Sabino, L. L., & Macusi, E. S. (2022). Closed season policy is only partly practiced in Surigao del Sur, Philippines. *World*, 3(4), 1067-1079.

Madeira, D., & Calado, R. (2019). Defining research priorities to detect live fish illegally collected using cyanide fishing in Indo-Pacific coral reefs. E*cological Indicators*, 103, 659-664.

Mamauag, R. E. P., & Ragaza, J. A. (2017). Growth and feed performance, digestibility and acute stress response of juvenile grouper (*Epinephelus fuscoguttatus*) fed diets with hydrolysate from milkfish offal. *Aquaculture Research*, 48(4), 1638-1647.

Marte, C. L., & Toledo, J. D. (2015). Marine fish hatchery: developments and future trends. In Resource Enhancement and Sustainable Aquaculture Practices in Southeast Asia: Challenges in Responsible Production of Aquatic Species: Proceedings of the International Workshop on Resource Enhancement and Sustainable Aquaculture Practices in Southeast Asia 2014 (RESA). A*quaculture Department, Southeast Asian Fisheries Development Center*. 189-200

Mayerle, R., Sugama, K., Runte, K. H., Radiarta, N., & Vallejo, S. M. (2018). Spatial planning of marine finfish aquaculture facilities in Indonesia. *Aquaculture zoning, site selection and area management under the ecosystem approach to aquaculture*, 222.

Md Noor, N., & Harun, S. N. (2022). Towards

Sustainable Aquaculture: A Brief Look into Management Issues. *Applied Sciences,* 12(15), 7448.

Megarajan, S., Ranjan, R., Ghosh, S., Xavier, B., Suresh, R. D., Chinnibabu, B., & Gopalakrishnan, A. (2022a). Technology for farming of Orange spotted grouper in marine cage culture systems. Marine Fisheries Information Service, Technical and Extension Series, (252), 17-22.

Megarajan, S., Ranjan, R., Xavier, B., Dash, B., Ghosh, S., & Gopalakrishnan, A. (2022b). Good Aquaculture Practices (GAP) in sea cage farming of Indian pompano and Orange spotted Grouper.

Mo, W. Y., Lau, R. S. S., Kwok, A. C. K., & Wong, M. H. (2016). Use of soybean meal and papain to partially replace animal protein for culturing three marine fish species: Fish growth and water quality. *Environmental pollution,* 219, 815-820.

Mo, W. Y., Man, Y. B., & Wong, M. H. (2018). Use of food waste, fish waste and food processing waste for China's aquaculture industry: Needs and challenge. *Science of the Total Environment,* 613, 635-643.

Monteclaro, H., Quinitio, G., Moscoso, A. D., Napata, R., Espectato, L., Anraku, K., & Ishikawa, S. (2018). Impacts of Typhoon Haiyan on Philippine capture fisheries and implications to fisheries management. *Ocean & Coastal Management,* 158, 128-133.

Mustafa, S. (2015). Sustainability of seafood production–challenges and the way forward. *Aquaculture Ecosystems: Adaptability and Sustainability,* 1-36.

Muzaki, A., Sembiring, S. B. M., Permana, G. N., & Mahardika, K. (2021). The development of the reproductive organs of the hybrid grouper cantik (*Epinephelus fuscoguttatus* x *E. polyphekadion*). *In IOP Conference Series: Earth and Environmental Science* 890 (1). IOP Publishing.

Nankervis, L., Cobcroft, J. M., Nguyen, N. V., & Rimmer, M. A. (2022). Advances in practical feed formulation and adoption for hybrid grouper (*Epinephelus fuscoguttatus*♀ × *E. lanceolatus*♂) aquaculture. *Reviews in Aquaculture*, 14(1), 288-307.

Ng, I., Bellwood, D. R., & Siqueira, A. C. (2022). Do currents shape global patterns of hybrid richness in coral reef fishes? *Global Ecology and Biogeography,* 31(12), 2524-2540.

Ninawe, A. S., Hameed, A. S., & Selvin, J. (2017). Advancements in diagnosis and control measures of viral pathogens in aquaculture: an Indian perspective. *Aquaculture International*, 25, 251-264.

Noh, C. H., Kang, M. J., & Yoon, S. J. (2019). Embryonic development and hatchability of red-spotted grouper (*Epinephelus akaara*)× giant grouper (*E. lanceolatus*)♂ hybrid at three incubation temperatures. *Aquaculture Research*, 50(11), 3477-3481.

Novriadi, R. (2019). Mini Review: Production and economics analysis of backyard production of Tiger grouper *Epinephelus fuscoguttatus* fingerlings in Situbondo, Indonesia. *Jurnal FishtecH,* 8(2), 58-71.

Nurliyana, M., Amal, M. N. A., Zamri-Saad, M., & Ina-Salwany, M. Y. (2019). Possible transmission routes of *Vibrio* spp. in tropical cage-cultured marine fishes. *Letters in applied microbiology*, 68(6), 485-496.

Ohta, I., & Ebisawa, A. (2015). Reproductive biology and spawning aggregation fishing of the white-streaked grouper, Epinephelus ongus, associated with seasonal and lunar cycles. *Environmental Biology of Fishes*, 98(6), 1555-1570.

Palanca-Tan, R. (2018). Aquaculture, poverty and environment in the Philippines. The Journal of Social, Political, and *Economic Studies*, 43(3/4), 294-315.

Palma, P., Takemura, A., Libunao, G. X., Superio, J., de Jesus-Ayson, E. G., Ayson, F., & Elizur, A. (2019). Reproductive development of the threatened giant grouper *Epinephelus lanceolatus. Aquaculture*, 509, 1-7.

Pang, G., Zhang, S., Liu, H., Zhu, S., Yuan, T., Li, G., & Huang, X. (2023). Hydrodynamic responses analysis for a new semi-submersible vessel-shape fish farm platform based on numerical simulation. *Frontiers in Marine Science,*

 DOI: https://doi.org/10.59120/drj.v14i2.109

10, 344.

Park, Y. J., Yoon, N. J., & Kyu, L. H. (2018). Effects of low salinity on growth, survival, and stress response in the longtooth grouper, *Epinephelus bruneus, and E. bruneus* × *E. lanceolatus* hybrid grouper.

Pathak, H., Mishra, J. P., & Mohapatra, T. (2022). Indian Agriculture after Independence. *Indian Council of Agricultural Research, New Delhi*, 110(001), 426.

Peralta-Milan, S., Baba, O., & Salmo III, S. G. (2020). Linking marketing of reef-sourced seafood with tourism: potential for improving fisheries management. *Philipp. Sci. Lett*, 13(2), 113-123.

Phạm, N. T., Amagai, T., Mushirobira, Y., Murata, R., & Soyano, K. (2022). Growth, sexual transition, and maturation of blacktip grouper Epinephelus fasciatus under long-term artificial rearing: Puberty and its associated physiological and endocrine changes. *Aquaculture*, 560, 738595.

Piah, R. M., Kadir, N. A., Kamaruddin, S. A., Azaman, M. N., & Ambak, M. A. (2018). Analysis of historical landing data to understand the status of grouper populations in Malaysia. *Malaysian Applied Biology*, 47(3), 49-58.

Pomeroy, R. (2007). Public policy For sustainable grouper aquaculture development in Southeast Asia. *Species and System Selection for Sustainable Aquaculture*, 461-476.

Pomeroy, R. S. (2002). The status of grouper culture in Southeast Asia. *SPC Live Reef Fish Information Bulletin*, (10), 22-26.

Ramírez-Ortiz, G., Balart, E. F., Reyes-Bonilla, H., Huato-Soberanis, L., Cortés-Fuentes, C., & Micheli, F. (2022). Greater resilience of reef fish assemblages in a no-take reserve compared to multi-use areas of the Gulf of California. *Progress in Oceanography*, 204, 102794.

Ranjan, R., Megarajan, S., Xavier, B., Bathina, C., Ghosh, S., & Gopalakrishnan, A. (2022a). Practical Manual on Seed Production of Orange Spotted Grouper and Indian Pompano.

Ranjan, R., Megarajan, S., Xavier, B., Bhaskaran Pillai, S., Bathina, C., Avadhanula, R. K., & Gopalakrishnan, A. (2022b). Enhanced larval survival in orange-spotted grouper (*Epinephelus coioides)* using optimized feeding regime. *Aquaculture Research*, 53(9), 3430-3440.

Rayner, T. A., Jørgensen, N. O., Blanda, E., Wu, C. H., Huang, C. C., Mortensen, J., & Hansen, B. W. (2015). Biochemical composition of the promising live feed tropical calanoid copepod *Pseudodiaptomus annandalei* (Sewell 1919) cultured in Taiwanese outdoor aquaculture ponds. *Aquaculture*, 441, 25-34.

Reverter, M., Tapissier-Bontemps, N., Sarter, S., Sasal, P., & Caruso, D. (2021). Moving towards more sustainable aquaculture practices: a meta-analysis on the potential of plant-enriched diets to improve fish growth, immunity and disease resistance. *Reviews in Aquaculture*, 13(1), 537-555.

Rimmer, M. A., & Glamuzina, B. (2017). A review of grouper (Family Serranidae: Subfamily Epinephelinae) aquaculture from a sustainability science perspective. *Reviews in Aquaculture*, 11(1), 58-87.

Rimmer, M. A., Sudja, W., Indradjaja, D. D., Giri, N. A., & Laining, A. (2017). Compound feeds for grouper aquaculture–why has adoption been so poor. *Aqua Culture Asia Pacific Magazine*, 12(5), 25-28.

Rutaisire, J., Nandi, S., & Sundaray, J. K. (2017). A review of Uganda and Indias freshwater aquaculture: Key practices and experience from each country. *Journal of Ecology and the Natural Environment*, 9(2), 15-29.

Schneider, H., Thiha, S., Pontillas, M., & Ponce de Leon, E. M. (2015). Socio-economic baseline assessment: Thayawthatangyi and Langan Islands, Myeik Archipelago, Myanmar.

Sen, S., Dash, G., & Bharadiya, S. A. (2019). First Record of Longspine Grouper, *Epinephelus longispinis* (Kner, 1864) from Gujarat, North-West Coast of India. *Thalassas: An International Journal of Marine Sciences*, 35(1), 287-289.

Shapawi, R., Abdullah, F. C., Senoo, S., & Mustafa, S. (2019). Nutrition, growth and resilience of tiger grouper (*Epinephelus fuscoguttatus*)× giant Grouper (*Epinephelus lanceolatus*) hybrid-a review. *Reviews in Aquaculture*, 11(4), 1285-1296.

Shen, G. M., Shi, C. Y., Fan, C., Jia, D., Wang, S. Q., Xie, G. S., & Huang, J. (2017). Isolation, identification and pathogenicity of Vibrio harveyi, the causal agent of skin ulcer disease in juvenile hybrid groupers *Epinephelus fuscoguttatus* × *Epinephelus lanceolatus*. *Journal of fish diseases,* 40(10), 1351-1362.

Shen, Y., Ma, K., & Yue, G. H. (2021). Status, challenges and trends of aquaculture in Singapore. *Aquaculture*, 533, 736210.

Shideler, G. S., & Pierce, B. (2016). Recreational diver willingness to pay for goliath grouper encounters during the months of their spawning aggregation off eastern Florida, USA. *Ocean & Coastal Management*, 129, 36-43.

Sim, S., Kongkeo, H., & Rimmer, M. (2005). Brief overview of recent grouper breeding developments in Thailand. *Aquaculture Asia*, 10(3), 24.

Sorphea, S., Kiessling, A., Barnes, A. C., Da, C. T., Lindberg, J. E., & Lundh, T. (2018). A field survey of smallscale cage and pond farming of Asian Seabass (L*ates calcarifer*) in Cambodia. *Livestock Research for Rural Development*, 30(7).

Sun, Y., Guo, C. Y., Wang, D. D., Li, X. F., Xiao, L., Zhang, X., & Zhang, Y. (2016). Transcriptome analysis reveals the molecular mechanisms underlying growth superiority in a novel grouper hybrid (*Epinephelus fuscogutatus*♀ × *E. lanceolatus*♂). *BMC genetics*, 17(1), 1-10.

Sun, Z., Tan, X., Xu, M., Liu, Q., Ye, H., Zou, C., & Ye, C. (2019). Liver transcriptome analysis and de novo annotation of the orange-spotted groupers (*Epinephelus coioides*) under cold stress. *Comparative Biochemistry and Physiology Part D: Genomics and Proteomics*, 29, 264-273.

Sutthinon, P., Thongprajukaew, K., Saekhow, S., & Ketmanee, R. (2014). Juvenile hybrid grouper (*Epinephelus coioides* × *E. lanceolatus*) are euryhaline and can grow in a wide range of salinities. *Aquaculture International*, 23, 671-682.

Tamat, W., Halim, D. S. N. P. H. A., & Pakar, E. F. B. (2019). Current status, issues and gaps of aquatic emergency preparedness and response systems practiced in Brunei Darussalam. In Aquatic Emergency Preparedness and Response Systems for Effective Management of Transboundary Disease Outbreaks in Southeast Asia: Proceedings of Asean Regional Technical Consultation, 20-22 August 2018, Centara Grand Central Ladprao, Bangkok, Thailand. Aquaculture Department, Southeast A*sian Fisheries Development Center*. 3-6

Tewfik, A., Babcock, E. A., Gibson, J., Perez, V. R. B., & Strindberg, S. (2017). Benefits of a replenishment zone revealed through trends in focal species at Glover's Atoll, Belize. *Marine Ecology Progress Series,* 580, 37-56.

Ting, K. H., Lin, K. L., Jhan, H. T., Huang, T. J., Wang, C. M., & Liu, W. H. (2015). Application of a sustainable fisheries development indicator system for Taiwan's aquaculture industry. *Aquaculture*, 437, 398-407.

Tookwinas, S. (1989). Review of knowledge on grouper aquaculture in South East Asia. *In Advances in Tropical Aquaculture, Workshop at Tahiti, French Polynesia,*

Tran, N., Rodriguez, U. P., Chan, C. Y., Phillips, M. J., Mohan, C. V., Henriksson, P. J. G., & Hall, S. (2017). Indonesian aquaculture futures: An analysis of fish supply and demand in Indonesia to 2030 and role of aquaculture using the AsiaFish model. *Marine Policy*, 79, 25-32.

Tucker, S. J., Kurniasih, E. M., & Craig, M. T. (2016). A new species of grouper (*Epinephelus*; Epinephelidae) from the Indo-Pacific. *Copeia*, 104(3), 658-662.

Turon, M., Angulo-Preckler, C., Antich, A., Præbel, K., & Wangensteen, O. S. (2020). More than expected from old sponge samples: A natural sampler DNA metabarcoding assessment of marine fish diversity in Nha Trang Bay (Vietnam). *Frontiers in Marine Science,*

7, 605148.

Van Truong, T., Neubert, K., Unger, P., Bui, T. Q., Ngo, H. T. T., Palm, H. W., & Kleinertz, S. (2017). Assessment of Epinephelus coioides (Hamilton, 1822) aquaculture systems in the Gulf of Tonkin, Vietnam, by using fish parasites. *Journal of Applied Ichthyology*, 33(6), 1125-1136.

Van Truong, T., Palm, H. W., Te Quang, B., Ngo, H. T. T., & Bray, R. A. (2016). Prosorhynchus Odhner, 1905 (Digenea: Bucephalidae) from the orange-spotted grouper *Epinephelus coioides* (Hamilton, 1822)(Epinephelidae), including *Prosorhynchus tonkinensis* **n.** sp., from the Gulf of Tonkin, Vietnam. *Zootaxa*, 4170(1), 71-92.

Villanueva, E. G., Hoevenaars, K., van Beijnen, J., Gonzales, A. P., Dolorosa, R. G., & Creencia, L. A. (2021). Protocol development for the improved hatchery propagation of Tiger grouper *Epinephelus fuscoguttatus* (Forsskål, 1775) in Palawan, Philippines. *The Palawan Scientist*, 13(1), 132-147.

Waludin, S. N., Mohamed, A. A., Phang, I. C., & Mukai, Y. (2018). Genetic diversity of the orange-spotted grouper (*Epinephelus coioides*) in Terengganu Malaysia based on mitochondrial cytochrome b sequence data. *Malaysian Applied Biology*, 47(6), 61-68.

Wang, Y. K., Li, C. C., Huang, K. Y., & Tsai, C. C. (2020). Can Aquaculture Ponds Be Managed as Foraging Habitats for Overwintering Water Birds? An Experimental Approach. *Sustainability*, 12(24), 10335.

Xiao, H., Liu, M., Li, S., Shi, D., Zhu, D., Ke, K., & Li, P. (2019). Isolation and characterization of a ranavirus associated with disease outbreaks in cultured hybrid grouper (♀ T*iger Grouper Epinephelus fuscoguttatus* ×♂ *giant grouper E. lanceolatus*) in Guangxi, China. *Journal of Aquatic Animal Health*, 31(4), 364-370.

Xie, B., Huang, C., Wang, Y., Zhou, X., Peng, G., Tao, Y., & Huang, L. (2021a). Trophic gauntlet effects on fisheries recovery: a case study in Sansha Bay, China. *Ecosystem Health and Sustainability*, 7(1), 1965035.

Xie, R. T., Amenyogbe, E., Chen, G., & Huang, J. S. (2021b). Effects of feed fat level on growth performance, body composition and serum biochemical indices of hybrid grouper (*Epinephelus fuscoguttatus* × *Epinephelus polyphekadion*). *Aquaculture*, 530, 735813.

Xu, J., & Li, D. (2021). Feeding behavior responses of a juvenile hybrid grouper, *Epinephelus fuscoguttatus* ♀× *E. lanceolatus*♂, to microplastics. *Environmental Pollution*, 268, 115648.

Yan, M., Leung, P. T., Gu, J., Lam, V. T., Murray, J. S., Harwood, D. T., & Lam, P. K. (2020). Hemolysis associated toxicities of benthic dinoflagellates from Hong Kong waters. *Marine pollution bulletin*, 155, 111114.

Yang, Y., Wang, T., Chen, J., Wu, X., Wu, L., Zhang, W., & Liu, X. (2021). First construction of interspecific backcross grouper and genome-wide identification of their genetic variants associated with early growth. *Aquaculture*, 545, 737221.

Yanuhar, U., Nurcahyo, H., Widiyanti, L., Junirahma, N. S., Caesar, N. R., & Sukoso, S. (2022). In vivo test of *Vibrio alginolyticus* and *Vibrio harveyi* infection in the humpback grouper (*Cromileptes altivelis*) from East Java Indonesia. *Veterinary World*, 15(5), 1269.

Yusoff, M., Hassan, B. N., Ikhwanuddin, M., Sheriff, S. M., Hashim, F., Mustafa, S., & Koh, I. C. C. (2018). Successful sperm cryopreservation of the brown-marbled grouper, Epinephelus fuscoguttatus using propylene glycol as cryoprotectant. *Cryobiology*, 81, 168-173.

Zhou, X., Zhao, X., Zhang, S., & Lin, J. (2019). Marine ranching construction and management in East China Sea: Programs for sustainable fishery and aquaculture. *Water*, 11(6), 1237.