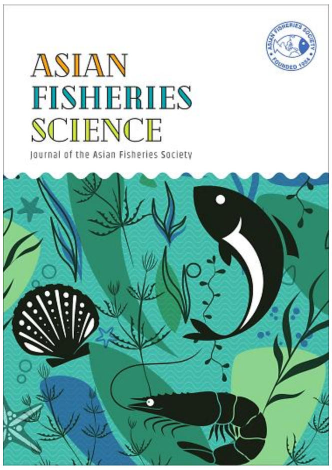

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Cost-Benefits of Grouper *Epinephelus fuscoguttatus* (Forsskål, 1775) Stock Enhancement and Sea-Ranching in Indonesia

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Abstract

Stock enhancement and sea-ranching of groupers are a potential solution to overfishing of wild grouper catches. Hence, it is vital to understand the costs and benefits of stock enhancement and sea-ranching. A simulation was conducted to estimate the cost and benefits of using brown marbled grouper *Epinephelus fuscoguttatus* (Forsskål, 1775) for stock enhancement in the Karimunjawa Islands, Indonesia. The major costs for stock enhancement were the purchase of fish and transportation to the release site. Overall, the calculations of a theoretical benefit of 1.27–1.69 USD per released fish were estimated for the year 2017/2018 based on 1000 released fish of 10 and 15 cm length at release. The theoretical benefit decreased to 0.83 USD per released fish under extreme climate conditions exemplified by El Niño. Although releasing 15 cm *E. fuscoguttatus* was more costly and generated less economic benefit, the likelihood of predation for the larger fish was much lower. When the economic benefit of grouper mariculture is compared with stock enhancement, the former provides an additional advantage, which is conservatively estimated at 0.62 USD per individual. Besides, the annual benefit from the stock enhancement was estimated to be of 550,000 USD per year from related tourism activities in Karimunjawa Islands.

Keywords: grouper, stock enhancement, sea-ranching, cost and benefit, Karimunjawa National Park

Introduction

Overfishing is a significant threat to marine species, ecosystems and global fisheries. A potential strategy to restore fish populations in overfished regions is stock enhancement and sea ranching, which is a relatively new method (Bell et al. 2008). Fish stock enhancement is defined as the release of cultured fish into the natural population to increase the stock size, while sea-ranching is similar but designed primarily for economic purposes (Bell et al. 2008). Stock enhancement was first introduced in Japan in 1762 for freshwater fish and in 1962 for marine fish (Masuda and Tsukamoto 1998). Since its introduction, several success stories of stock enhancement have been reported, e.g. for striped mullet *Mugil cepahlus* Linnaeus 1758, in Hawaii (Leber at al. 1995), southern scallops *Pecten novaezelandiae* Reeve, 1852, in New Zealand (Lorenzen 2008), brown tiger prawn *Penaeus esculentus* Haswell, 1879, in Western Australia (Loneragan et al. 2006), salmonids (chum salmon *Oncorhynchus keta* (Walbaum 1792), pink salmon *O. gorbuscha* (Walbaum, 1792), and masu salmon *O. masou* (Brevoort 1856)) (Masuda and Tsukamoto 1998) and other finfish (Kitada and Kishino 2006) in Japan.

Groupers have significant economic value because they are widely consumed in the seafood restaurant around the world (Mous et al. 2000; Sadovy and Vincent 2002). Wild-caught grouper generally fetch a higher price than the cultured fish. According to Rachmansyah et al. (2009), the difference in price is due to consumer preference for the "wild grouper taste". Chan and Johnston (2007) reported that over 70 % of consumers in Hong Kong seafood restaurants preferred wild-caught fish. The relatively high survival rate of wild groupers during post-harvest transportation also adds to their marketable value. These high market prices spur fishers to target wild grouper resulting in increasing fishing effort even in overfished stocks (Yulianto et al. 2015a). This escalating fishing pressure impacts wild groupers population and habitat and can have ripple negative consequences for ecosystem (Sadovy et al. 2013).

Stock enhancement and sea-ranching of groupers can potentially reduce the problems caused by constant high wild grouper catches, though they cannot substitute for sensible fishery management for sustainable use stocks. Another essential factor of stock enhancement is the ecological benefit at the release site. The benefit of stock enhancement includes recovery of the depleted stock, protection and conservation of endangered species, and improved knowledge on the ecology, life history and environmental situation of important marine species (Lorenzen et al. 2010; Leber et al. 2012). Obolski et al. (2016) also showed that restocking grazing fish could theoretically support coral reef recovery.

Stock enhancement and sea-ranching for grouper are also hypothesised to be much lower than the costs to produce cultured grouper in grow-out mariculture (Purcell et al. 2012), since there are no costs of maintaining the grow-out facilities, and providing feed for the fish kept under mariculture conditions. However, before adopting stock enhancement and sea-ranching as a solution for boosting grouper stocks and fisheries, it is vital to understand the costs and benefits of this approach. Accordingly, the objective of this study was to calculate the costs and benefits of stock enhancement of brown marbled grouper *Epinephelus fuscoguttatus* (Forsskål, 1775) in Indonesia.

Materials and Methods

The costs of stock enhancement conducted in Karimunjawa Islands (Fig. 1) were calculated based on juvenile grouper prices and transportation costs for stock enhancement of 1,000 grouper in year 2017/2018. The juvenile price used in this study was based on a market survey of the fish sold at the mariculture centre in Jepara District, the nearest mariculture centre to Karimunjawa Islands. The transportation cost was based on current boat rental price in Karimunjawa Islands.

The economic benefits of stock enhancement were calculated based on estimated survival and growth rates of the stocked grouper, and their future potential fishery and tourism value. The estimated fishery values were based on the number of fish surviving to 0.57 kg by time t, due to the highest price of grouper was between 0.5 and 1 kg, multiplied by the estimated future market value per fish (V) (i.e. Nt * V). The fish survival rate to 0.57 kg for 10 cm and 15 cm juveniles under normal (i.e. business as usual) conditions were estimated using equation 1:

$$N_t = N_0 \, EXP(-z * t) \qquad (1)$$

Where N_t is the number of fish after time t, and N_0 is the number of fish at the beginning of the stock enhancement, and Z is the total mortality. In this case, Nt was estimated based on stocking 1,000 fish, such that N_0 = 1,000. Time t was parameterised as the time at which the fish reach harvestable weight (0.57 kg), based on equations 2 and 3:

$$L(t) = L_{inf} (1 - EXP(-k * (t - t_0)) \qquad (2)$$

$$W = a L^b \qquad (3)$$

using published natural mortality estimates (m = 0.445 and 0.460 per year), growth parameters (L_{inf} = 97.48 cm, k = 0.27, t_0 = -0.44), and length-weight relationships (a = 0.008, b = 3.16), according to Kurnia (2012). Based on this, it is estimated that 10 cm juvenile grouper will reach harvestable weight after 1.2 years, while 15 cm juvenile grouper will reach harvestable weight after 1 year.

For total mortality, Z, fishing mortality was assumed to be zero before the fish reached 0.57 kg, such that Z is equal to natural mortality. Natural mortality, M, for the two fish size classes (10 cm and 15 cm) was estimated according to equation 4 from Sattar et al. (2008):

$$M = 25L^{-0.5} + 0.15 \qquad (4)$$

where L is length in cm.

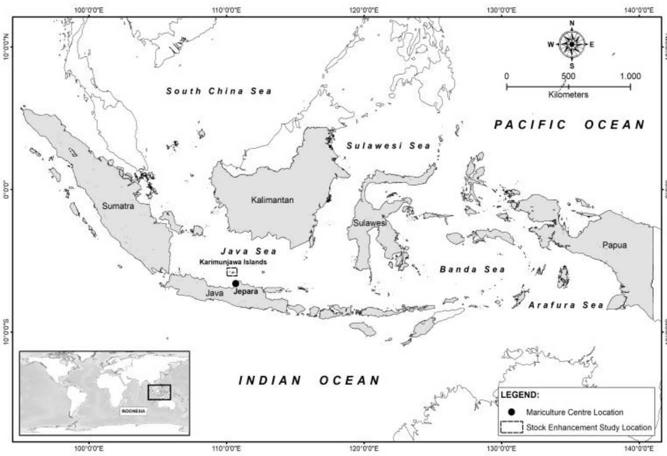

Fig. 1. Map of mariculture centre and stock enhancement study location.

Natural mortality was also estimated for extreme conditions (e.g. El Niño), according to growth parameters from Kurnia (2012) and maximum sea surface temperature in Karimunjawa (34.0 °C sources: NOAA NMFS SWFSC ERD 2017), using equations from several studies (Alverson and Carney

1975; Pauly 1980; Chen and Watanabe 1989; Jensen 1996, 1997; Then et al. 2015).

A willingness to pay survey with tourists visiting Karimunjawa for snorkelling and diving was conducted by interviewing 41 tourists, to explore additional benefit from grouper stock enhancement and sea-ranching. The tourists were asked how much their trip currently cost, and how much extra they would be willing to pay more for snorkelling and/or diving at sites which have a higher abundance of groupers (large reef fish).

Results

The major costs for brown-marbled grouper stock enhancement were the purchase of the fish and the transportation cost to the release site. The price of 10 cm and 15 cm grouper were 10,000 IDR (0.7 USD) and 25,000 (1.8 USD) IDR per fish (1 USD = 14,000 IDR), respectively. The costs of transportation and maintenance were estimated at 1,000 IDR (0.07 USD) per fish. However, the transportation costs could decrease with the increasing number of fish, due to fixed costs for a certain number of fish. Based on these values, the total costs of the stock enhancement for 1000 grouper of 10 cm and 15 cm length were estimated at 11,000,000 IDR (785.7 USD) and 26,000,000 IDR (1857.1 USD), respectively (Table 1).

Based on natural mortality estimates from Kurnia (2012), for fish released at 10 cm in length, around 590 out of 1,000 fish will have survived after 1.2 years. For those released at 15 cm, an estimated 640 fish will have survived after 1 year (Fig. 2 and Table 1). Using the different natural mortalities from Sattar et al. (2008) and the above equation (M = 0.21 and 0.20), from 1000 groupers released at 10 cm, a total of around 770 fish are most likely to survive after 1.2 years, while about 820 individuals will have survived from 1000 specimens released at a size of 15 cm after 1 year. When the maximum mortality of brown-marbled grouper (0.597 per year at 34 °C) during high water temperatures (El Niño) was used, the surviving number of fish of 10 cm and 15 cm fish were 498 and 550 individuals, respectively, under the absence of fishing mortality (Fig. 2).

Based on the calculation of the economic benefits, the stock enhancement or sea-ranching of 10 cm and 15 cm individuals can theoretically produce around 328 and 365 kg of grouper respectively, with the stocking of 1000 individuals each and using the natural mortality from Kurnia (2012). The theoretical benefit of the stock enhancement or sea-ranching activity with 10 and 15 cm sized grouper is around 28 million IDR (2027 USD) and 18 million IDR (1274 USD) per production period (1.2 and 1 year, respectively), or 24 million IDR (1690 USD) and 18 million IDR (1274 USD) per year, respectively (Table 1). Taking the natural mortality from Sattar et al. (2008), the theoretical benefit of the stock enhancement or sea-ranching activity with 10 and 15 cm sized grouper was 34 million IDR (2497 USD) and 29 million IDR (2136 USD) per year, respectively. When the maximum natural mortality was applied, based on extreme climatic conditions, the theoretical benefit of stock enhancement and sea-ranching decreased to 19 million IDR (10 cm; 1334 USD) and 12 million IDR (15 cm; 832 USD). These values refer to a theoretical benefit of at least 1.27 USD per released fish per year according to the models under normal condition and decrease to 0.83 USD per released fish under extreme climate conditions (e.g. El Niño).

The feedback from the tourists showed that they regularly spent a median of 383,333 (range 233,333–1,256,000) IDR or 27.38 (range 16.67–89.71) USD per day on visiting the beach, coral reefs, and viewing reef fish in Karimunjawa Islands. They stayed between 3, 4, and 5 days per trip. All visitors were willing to spend an additional median of 100,000 (range 20,000–500,000) IDR or 7.14 (range 1.43–35.71) USD per trip if they can snorkel or dive at a site with a higher abundance of grouper (reef fish).

Discussion

The costs and benefits of grouper stock enhancement and sea-ranching depend on the released grouper size and the survival of the fish. Estimating the economic benefits of stock enhancement is not trivial (Uwate and Shams 1997), because it needs to address several assumptions. The natural mortalities derived from the equation are most likely to be realistic for natural free-living groupers since they were calculated from the length-frequency distributions of *E. fuscoguttatus*. The length equation and resulting values used by Sattar et al. (2008) can be considered more precise than those used by Kurnia (2012). On the other hand, the natural mortality from Sattar et al. (2008) seems very low in which the survival of 770—820 fish out of 1000 after 1.2 years is highly unlikely. Hence, it is more realistic to use the natural mortality from Kurnia (2012) for the economic benefits of sea-ranching and stock enhancement. The author also stated that the natural mortality used in his study has taken into account local conditions in the Java Sea. In addition, the maximum natural mortality proposed by Pauly (1980) (survival of 489—550 individuals) can be considered an extreme condition during that particular study because the sea surface temperature used in the calculation was 34 °C (El-Niño 2010). Consequently, both the natural mortality from Kurnia (2012) and the maximum natural mortality for the calculation were used.

Although the benefit of the stock enhancement with 10 cm groupers is theoretically higher than that of the 15 cm fish, the released smaller groupers are less

Table 1. The economic costs and benefits of sea-ranching in Karimunjawa Islands (inflation is not considered in the calculation).

No	Description	Note	Scenario 1			Scenario 2		
			Kurnia (2012)	Sattar et al. (2008)	Predation + Kurnia (2012)	Kurnia (2012)	Sattar et al. (2008)	Maximum M
1	Number of fish (initiated time)	N_0			1,000			1,000
2	Size (cm)				10			15
3	Price per fish (IDR)	P			10,000			25,000
4	Total price of fish at initiated time (IDR)	TP = N_0 * P			10,000,000			25,000,000
5	Transportation and maintenance (IDR, per fish)	Tr			1,000			1,000
6	Total price of transportation per 1000 (IDR)	TT = N_0 * Tr			1,000,000			1,000,000
7	Total cost (IDR, per 1000 fish)	TC = TP + TT			11,000,000			26,000,000
8	Natural mortality (M)	M	0.460	0.213	0.460	0.445	0.202	0.597
9	Fishing mortality (F)	F	0.00	0.00	0.00	0.00	0.00	0.00
10	Total mortality (Z)	Z = M + F	0.46	0.21	0.460	0.45	0.20	0.597
11	Time to captured size (year)	t	1.20	1.20	1.20	1.00	1.00	1.00
12	Number of fish at captured size (0.57 kg) (ind)	Nt = No * EXP (-Z * t)	576	774	461	641	817	550
13	Total Weight (kg)	TW = Nt * 0.57	328	441	263	365	466	314
14	Price at captured size (IDR kg^{-1})	Pt	120,000	120,000	120,000	120,000	120,000	120,000
15	Total price at captured size (IDR)	TR = TW * Pt	39,384,519	52,956,889	31,532,400	43,832,380	55,909,429	37,651,501
16	Benefit (IDR)	R = TR - TC	28,384,519	41,956,889	20,532,400	17,832,380	29,909,429	11,651,501
17	Benefit per year (IDR)	Ry = R : t	23,653,766	34,964,074	17,110,333	17,832,380	29,909,429	11,651,501
18	Benefit per year (USD)	Ry = R : t	1690	2497	1222	1274	2136	832

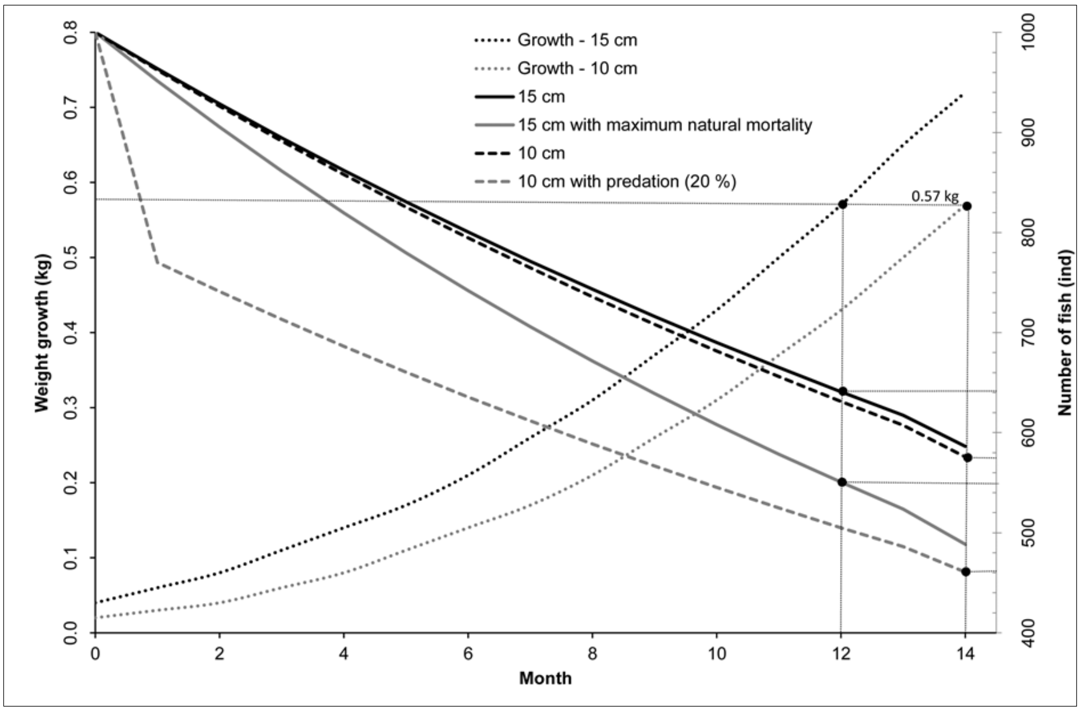

Fig. 2. Growth of 10 and 15 cm brown-marbled grouper *Epinephelus fuscoguttatus* and estimated numbers of fish that are calculated from the fish population model for 15 cm, 15 cm (with maximum natural mortality), 10 cm, and 10 cm with predation.

likely to survive, due to limited opportunity for adaptation. Thus, presumably a higher mortality of the smaller *E. fuscoguttatus*, compared to those from the natural population under the presence of predators, e.g. larger grouper (López and Orvay 2005; Yulianto et al. 2015b). Masuda and Ziemann (2003) suggested defining at critical size of fish to be released for stock enhancement since smaller fish have less capability to survive and larger fish are poorly capable of adapting a new environment despite better in avoiding predators. Yulianto et al. (2015b) suggested that, based on field observations, the minimum size of released brown-marbled grouper should be 15 cm, to minimise predation risks and optimise the yield from grouper stock enhancement. Since the 15 cm brown-marbled groupers can better adapt to the environment and the presence of predators after release (Yulianto et al. 2015b), 15 cm may be the critical size. Consequently, the natural mortality from wild individuals was reasonable to be used in the calculation for the 15 cm fish, along with careful estimate based on extreme environmental conditions and maximum mortality.

The observation suggested that the 10 cm grouper can easily fall prey to larger fish, thus the 15 cm grouper can be assumed to have better survival about 20 % than the 10 cm one (if 1 out of 5 fish with a 10 cm size additionally falls prey to a predator, compared to a 15 cm fish size, a most likely scenario). The release of smaller fish of 10 cm will result in lower survival of 461 fish after 1.2 years, as compared to the release of bigger fish of 15 cm with survival of 550 fish. Moreover, the theoretical benefit of 10 cm released fish decreased to around IDR 17 million (1222 USD) per year, which is lower than the theoretical benefit of the 15 cm fish release with the natural mortality as reported by Kurnia (2012). The observation of the reef showed that 10 cm fish easily fall prey to larger groupers (Yulianto et al. 2015b), and indicated that the real mortality seemed to be much higher. Consequently, the better option for stock enhancement and sea-ranching of *E. fuscoguttatus* is the release of 15 cm fish. However, the available size of grouper in Indonesian mariculture centres is usually 10 cm or less, and the fish need to be kept in the net cages for several weeks to reach the size of 15 cm. This requires special cultivation techniques, such as adding hiding places into the cages or tanks for the fingerlings (Yulianto et al. 2015b). The cultivation in the net cage would lead to higher production costs of 15 cm *E. fuscoguttatus*, making them more expensive and involving higher possible risks, such as the potential transfer of parasites from the farms into the wild (Rueckert et al. 2010) through the larger sized fish.

Based on calculations, a stock enhancement using 10,000 15 cm groupers could generate at least 6,200 USD or 86.8 million IDR per year (1800 USD or 25.2 million IDR per year at the maximum mortality/extreme condition), when the 15 cm grouper reached 34 cm or > 500 gram. According to fishers and traders, brown marbled grouper reached the highest price per weight when the fish is between 0.5 and 1 kg. Moreover, it can reduce the risk of ciguatera when the fishers catch *E. fuscoguttatus* at a smaller size, since the risk of ciguatera is lower for smaller fish (e.g. < 1000 gram) (Chan 2014, 2015). When the benefit results were simplified, the stock enhancement activity could produce a minimum benefit of 1.27 USD per year per released of 15 cm fish, and 0.83 USD at the maximum natural mortality according to life history as reported by Kurnia (2012). These benefits will increase if more fish are released for stock enhancement due to reduced transportation costs per fish. The benefit for a released 10 cm grouper would be 1.69 USD, only if both sizes had the same survival rate. This result fulfils the hypothesis that the economic benefit of stock enhancement is higher than that of only cultured *E. fuscoguttatus* which can produce an annual benefit between 0.41 USD per fish for medium-sized mariculture sites and 0.65 USD per fish for larger mariculture systems (Afero et al. 2010). The lower economic benefit of cultured grouper in Afero et al. (2010) is primarily influenced by the lower price of cultured grouper and the higher costs of the mariculture facilities to maintain the cultivated fish for a longer period, both of which are not relevant in stock enhancement programs. The difference between the minimum benefit of grouper from stock enhancement (1.27 USD) and the maximum benefit (0.65 USD) for the maricultured one, totalling 0.62 USD (0.18 USD at the maximum natural mortality), is a result of the fish growth without any costs in nature.

The benefit derived from calculation does not necessarily profit the grouper fishers or the sea-ranching institution because not all fish from stock enhancement are caught by the fishers or sea-ranching institutions. However, the benefit in this calculation is the theoretical value of the fish that can be produced throughout the program of stock enhancement or sea ranching. These calculations demonstrate that governmental grouper stock enhancement provides benefits over and above the costs for the fish and the release, additional direct economic benefit to local fishers and small communities, depending on the fisheries resources. That amount would be available as an economic incentive for grouper fishers, thus improving the survival of the released fish and grouper population protection or marine protected area effectiveness, also in Karimunjawa National Park (Campbell et al. 2013). This would support the implementation of grouper stock enhancement when the grouper fishers are involved right from the beginning of these activities because they are the recipients as well as drivers (Garaway et al. 2006). Through this, the fishermen can realise a direct impact of stock enhancement and receive additional income. Lessons learned from community-based stock enhancement in Japan (Tomiyama et al. 2008) demonstrated this fishermen involvement as an important factor of successful stock enhancement programs. The Government of Indonesia might also support the existing hatchery facility/mariculture centre in the same way to produce fingerlings which are ready for stock enhancement according to habitat adaptation and predation avoidance, also an investment finally benefiting the local fishermen and grouper stock users.

Additional benefits of stock enhancement and sea-ranching are linked to tourism activities (Lorenzen et al. 2010; Leber et al. 2012), such as recreational fishing and diving/snorkelling. Grouper is one of the favourite reef fish for recreational fishing in Indonesia (Pamungkas 2018) and most tourists visiting

Karimunjawa snorkel/dive for the coral reef and reef fish. In 2017, as many as 77,000 visitors (source: Tourism Information Centre Jepara 2017) visited Karimunjawa, and this generated an economic benefit of at least 88.5 billion IDR (6.3 Million USD) assuming that all visitors stayed there for 3 days on average. Taking this as a baseline, successful stock enhancement can potentially generate an additional benefit of 7.7 billion IDR (550,000 USD), because most visitors are willing to pay an additional 100,000 IDR per trip if they can snorkel or dive at a site with a higher abundance of reef fish (e.g. grouper). In addition, this activity may attract more tourists, because they usually prefer to dive at sites with higher fish abundance and the presence of large predators, thus generating further additional benefit. Grafeld et al. (2016) demonstrated that divers in Guam were willing to pay more for improved fish biomass. Stock enhancement in combination with marine protected areas (such as Karimunjawa National Park) or at remote islands, where the fishing pressure is lower, the measures as suggested here would even further improve the anticipated positive effects through the released animals, reducing fishing mortality and supporting recreational activities. Additionally, several studies have demonstrated that besides economic benefits, stock enhancement also has additional advantages, such as ecological benefit (Lorenzen et al. 2010; Leber et al. 2012; Obolski et al. 2016). Groupers function as predators and drive reef fish assemblages in the coral reef ecosystem (Boaden and Kingsford 2015) and have predator carrying capacity (Valdivia et al. 2017), thus enhancing grouper stock size will have the additional benefit that the present study does not calculate and consider.

Conclusion

The major costs for brown-marbled grouper stock enhancement were only the purchase of the fish and the transportation cost to the release site. The theoretical benefit of the stock enhancement or sea-ranching activity with 10 and 15 cm sized groupers and calculated for 1000 fish was around 24 million IDR (1690 USD) and 18 million IDR (1274 USD) per year, respectively, based on prices calculated for 2017/2018. Under maximum natural mortality, the theoretical benefit of the 15 cm fish stock enhancement declined to 12 million IDR (832 USD). Although the calculated benefit with 10 cm groupers was higher than that of the 15 cm sized fish, the possibility of the 10 cm grouper to survive was low. When the predation of 10 cm fish was taken into account, the number of surviving fish was lower than that of the 15 cm sized fish under the maximum natural mortality. Comparison with the economic benefit of 0.65 USD per produced fish from a mariculture site, stock enhancement or sea-ranching generates an additional benefit of 0.62 USD from nature or 0.18 USD under extreme conditions. The additional income generated can be used by the stakeholders invest in future stock enhancement activities and support mariculture development. Stock enhancement can positively contribute to tourism activities and potentially generate an additional benefit of 550,000 USD annually in the Karimunjawa Islands.

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