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Increased production of green mussels (*Perna viridis*) using longline culture and an economic comparison with stake culture on the north coast of Java, Indonesia

Sri Rejeki[1] | **Adolphe O. Debrot**[2,3] | **Anneke M. van den Brink**[2] | **Restiana W. Ariyati**[1] | **Lestari Lakshmi Widowati**[1]

[1]Aquaculture Department, Faculty of Fisheries and Marine Sciences, Diponegoro University, Jl. Prof. H. Soedarto S.H, Tembalang, Semarang, Indonesia

[2]Wageningen Marine Research, Wageningen University and Research, IJmuiden, the Netherlands

[3]Marine and Animal Ecology group, Department of Animal Sciences, Wageningen University, Wageningen, the Netherlands

Correspondence
Adolphe O. Debrot, Wageningen Marine Research, Wageningen University and Research, Postal address: P.O Box 68, 1970 AB IJmuiden, the Netherlands.
Email: dolfi.debrot@wur.nl

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Abstract

The effectiveness of green mussel (*Perna viridis*) cultivation was compared between longline culture and the traditional bamboo stake method using different mussel densities in a rural area on the north coast of Java, Indonesia. The study took place in a rural area about 2 km north-east from the city of Semarang where unsustainable shrimp and fish pond culture in the past has led to massive mangrove loss, spiralling environmental degradation and socio-economic disintegration. Mangrove-friendly alternatives for a sustainable socio-economic recovery of local livelihoods are urgently being sought. Longlines were more successful than the stake method in spat collection. Longlines also showed a small but significantly higher relative weight gain and specific growth rate for mussels than bamboo stakes. Mussels in lower densities showed higher survival and grew to larger individual sizes, but initial seeding density had no significant effect on relative weight gain or specific growth rate per stocking. Slightly lower set-up costs and time investment and somewhat higher yields for longlines give an almost twofold higher income per time unit of own time invested by the farmer for longline culture over the traditional stake culture method. The profitability of mussel culture using the stake method is below the average hourly wage for skilled labour, but above that when using the longline method. We conclude that green mussel culture using the longline system is feasible as an alternative to less sustainable forms of livelihood for the local communities in mangrove areas.

KEYWORDS

alternative livelihood, bamboo stake method, green mussel *Perna viridis*, growth, longline culture, mangrove, spat collection

1 | INTRODUCTION

The green mussel, *Perna viridis*, is an excellent source of protein, fat and carbohydrates (Chakraborty et al., 2016), making it a popular source of food for local communities, throughout South-East Asia, including Indonesia. Because the mussel reproduces throughout the year, requires no supplemental food input, grows to harvestable size in about six months (Litasari, 2002) and requires no mangrove removal for pond construction, it is particularly promising as a sustainable seafood product on erosion-sensitive mangrove coasts (Litasari, 2002). Mussel culture also does not require highly sophisticated techniques, knowledge or equipment, which makes it particularly suitable for use in small-scale artisanal settings (bin Sallih, 2005). However, Indonesia lags far behind in the culture of molluscs (Lymer et al., 2010) while culture technology innovation has apparently been a longstanding impediment to the sector (Lovatelli, 1988) and with few exceptions (e.g. Noor et al., 2019), little recent work has been done on mussel culture in Indonesia.

In Indonesia, green mussel cultivation occurs in sheltered marine mangrove waters and traditionally only involves the use of bamboo stakes. In the Demak Regency, north-east of Semarang on the northern coast of central Java, unsustainable shrimp and fish pond culture in the past has led to massive mangrove loss, spiralling environmental degradation and socio-economic disintegration (Wilms et al., 2017). Severe erosion of the coast has rendered much of the area unsuitable for pond cultivation, and mangrove-friendly alternatives for a sustainable socio-economic recovery of local livelihoods are urgently being sought (e.g. Ariyati et al., 2019). Alternatives potentially include the revitalization of nearshore fisheries based on the nursery function of mangroves (Anneboina & Kumar, 2017; Hutchison et al., 2014), mangrove ecotourism (Satyanarayana et al., 2012), sustainable harvest of mangrove forest products (Feurer et al., 2018; Kusmana, 2018) or a combination of these. The objectives of this project were to conduct feasibility trials on developing green mussel culture as an alternative livelihood for the impoverished coastal fishing communities of Demak, Java. The green mussel is already being harvested from man-made structures in the surrounding areas and, as is the case with several other bivalves, is a well-established local food (Noor et al., 2019). In this study, we compare spat settlement, survival and growth to market size between longline rope culture technique used elsewhere and the traditional stake ('rompong') method.

2 | MATERIALS AND METHODS

The study was done in Morosari Village, on the northern coast of Central Java, Indonesia, just 2 km north-east of Semarang in the coastal zone of the Demak Regency (6°55'43.6"S 110°29'00.4"E). The area was selected based on its physical suitability for aquaculture and the absence of potential interference from other fishing activities (Rejeki, 2009). The experimental site had an average depth of 0.77 m, temperature of 29.8–30.2°C, salinity 27.7–38.4 ppt and current speed of 8.0–15.0 cm.s^{-1}. Dissolved oxygen was 5.4–6.2 mg.L^{-1},

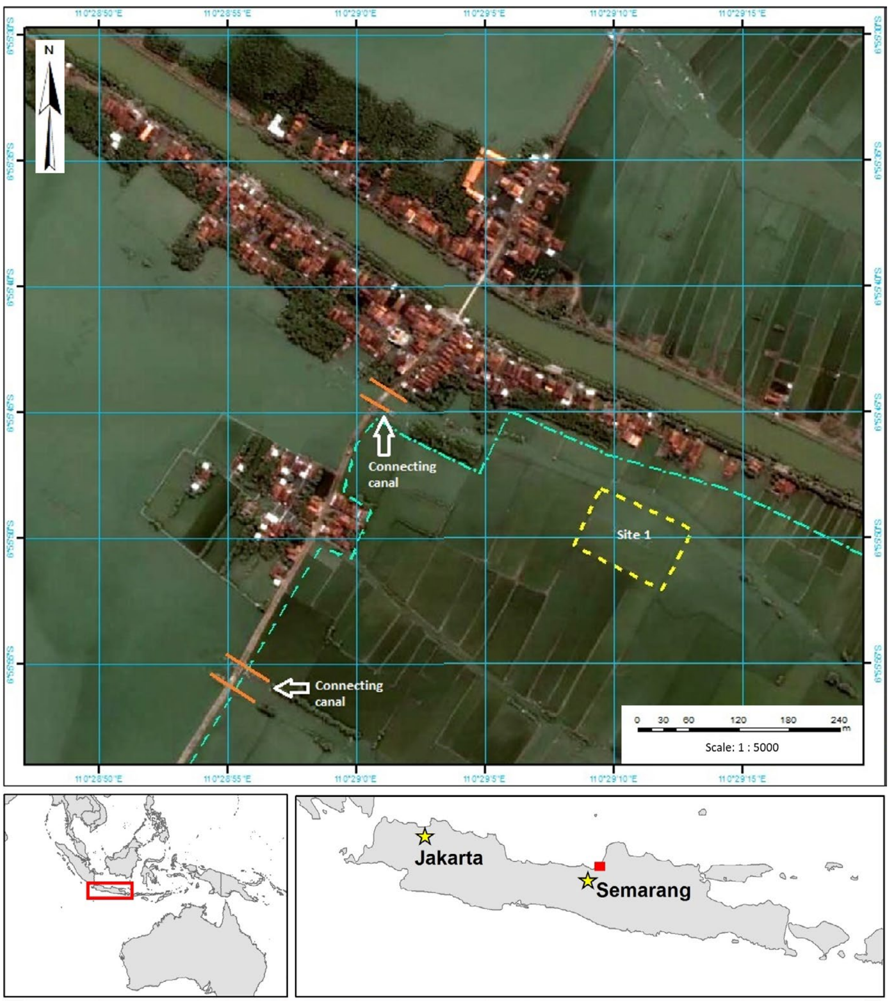

FIGURE 1 Map of the study site for experimental mussel culture at Morosari village, Demak, on the north coast of Java, Indonesia

and pH was 7.1–7.8, while average ammonia and phosphate concentrations were 0.105 ppm and 0.590 ppm respectively (Rejeki, 2011). The site was connected to the open sea through several canals of about 20 m in width (Figure 1).

In the stake method, culture takes place using 200-cm-long bamboo stakes stuck into the sediment 60 cm apart in water depths of 40–70 cm (Figure 2a). The spat collectors consisted of 100-cm pieces of natural palm fibre rope, one cm in diameter (surface area: 314 cm^2). They were suspended from their middle from the longlines or stakes, and total settlement was assessed for two months. In the grow-out experiment, one mussel stocking was attached at both ends vertically to each stake, approximately 30–40 cm from the bottom. Longlines consisted of 7.5-mm-diameter natural palm fibre rope. The rope was suspended between two stakes along the water surface. The longlines were three metres, but effective area submerged was about two metres. Five mussel stockings were suspended from the longline approximately 30–40 cm from the bottom and 30–50 cm apart (Figure 2b). Four of these units were used in the same area and simultaneously with the 20 stakes.

Bamboo stakes and longlines were assembled in February and March 2009. Spat collection involved 20 units of both bamboo stakes and longlines, while the grow-out experiment involved four treatments and six replications for each of the two methods. After approximately 30 days, the spat (average 4.3 g each) was removed from the bamboo stakes and longlines using a spatula and scissors to cut through the byssus threads. The spat was placed into mussel stockings and then attached to the structures so that the mussels were constantly submerged. The mussel stockings were gunny sack woven 25-cm plastic nets with a width of 20 cm and a mesh size of ± 1.5 mm, obtained free of charge as waste packaging. During the grow-out cycle, there was no possibility for the mussel to exit the stocking. Our use of mussel stockings in conjunction with longlines differs from the practice elsewhere where the mussels are typically attached to 1-m-long suspended ropes instead (Velayudhan et al., 2007; Mohamed, 2015). Mussel stockings were filled with 20, 30, 40 or 50 individuals spat per stocking and left for 75 days after which they were retrieved.

Mussel survival (in terms of % alive), total weight gain during the experiment until harvest (g) and specific weight gain per mussel stocking (%.mo^{-1}) were recorded. The results of each treatment and density combination were then compared using ANOVA to compare cultivation methods. We measured the number of spat collected, as well as the survival, total weight gain, mean mussel size and specific rate of weight increase (SGR) in for the mussel stocking. The number and weight (g) of spat were recorded per bamboo stake ($n = 20$) and longline unit ($n = 20$). Per cent survival of the mussels was recorded at the end of the experiment (75 days) and arcsine-transformed for statistical testing by factorial ANOVA, using $p \le .05$ as the criteria for significant differences.

The mussels within each stocking were cleaned of fouling organisms allowed to dry and weighed together. The total mussel biomass (including shells) and average weight per mussel were calculated for the duration of grow-out. Specific growth rate (SGR) of the mussels per mussel stocking (in terms of weight) was expressed as the

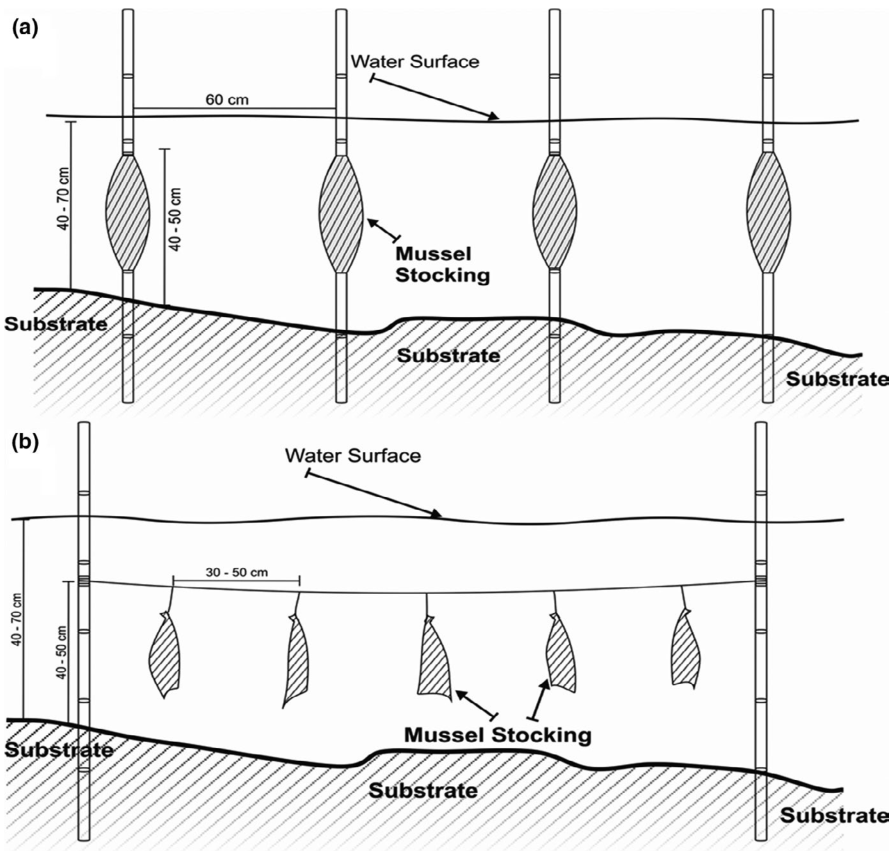

FIGURE 2 The bamboo stake method (a) and the longline method (b) used in the experiment to support the mussel stockings used for culture trials

percentage of the difference in log-transformed final weight and initial weight divided by the time interval according to the following formula:

$$SGR = \frac{\ln W_t - \ln W_0}{t} \times 100\%;$$

where SGR = specific growth rate (%.month^{-1}); Wt = final weight (g); W0 = initial weight (g); and t = growing period (months).

Using locally provided information on costs of labour and materials, production rates and selling price, we compared the profitability of the stake and longline culture methods.

The authors confirm that the ethical policies of the journal, as noted on the journal's author guidelines page, have been adhered to. The US National Research Council's guidelines for the Care and Use of Laboratory Animals were followed.

3 | RESULTS

Spat settlement densities (±1 *SD*) for longlines averaged 213 ± 109 individuals per settlement rope or 6,786 ± 3,476 ind.m^{-2}, while bamboo stakes collected significantly fewer for an average of 76 ± 15 individuals per settlement rope and 2,412 ± 484 ind.m^{-2} (Figure 3). The method of spat collection had no effect on the average biomass per individual spat, and individual spat had an average weight of 4.3 g on both the longline and bamboo stake collectors. Mussel survival during grow-out was comparably high for both methods (90%–92%) and did not differ significantly ($p > .05$) (Figure 4a). Weight gain per mussel was significantly higher for longlines (mean = 24.3g) than for bamboo stakes (mean = 22.9 g; $p \le .05$) (Figure 4b). Hence, cultivation method also significantly affected SGR (86% month^{-1} for longlines and 83% month^{-1} for the stakes) ($p \le .05$) (Figure 4c) and relative total weight gain of the mussel stockings (751% for the longline and 707% for the stake method) ($p \le .05$) (Figure 4d). Mussels in the lowest density showed a significantly higher average weight gain ($p \le .05$) (Figure 3b). However, differences in stocking density did not significantly affect relative weight gain per mussel stocking SGR ($p > .05$) (Figure 4c), or the total mussel biomass per stocking ($p > .05$) (Figure 4d).

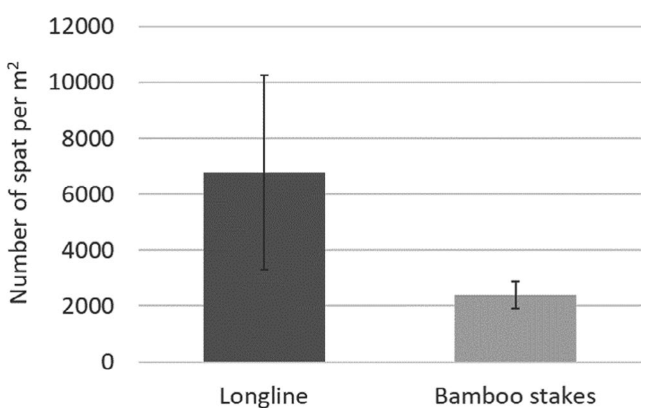

FIGURE 3 Spat settlement density (ind.m^{-2} ± 1 *SD*) on collectors suspended from longlines and bamboo stakes

The official high school-level minimum wage for Demak in 2019 was IDR 2,432,000/month. For skilled labour, the daily wages are IDR 85,000–100,000, whereas the wages for an unskilled fisherman's assistant were IDR 50,000/d (Bagus Maulana, personal communication). Typical 7–8 cm diameter bamboo poles on the market are 5–6 m, cost IDR 8,000/pcs and can yield three suitable stake sections (IDR 2,333/stake). Natural jute rope of one cm diameter costs IDR 1,000 per m. Rope length used per stake was 50 cm and per longline was 8.5 m (including 2.5 m for suspending the stockings). Material costs for the set-up of a unit of 80 stockings differed between the stake and rope culture. Using stakes, the rope costs were less than with longline culture, but the material and labour costs involved (including purchase, sawing to size, transport and placement) of the stakes were ultimately higher (Table 1). Due largely to attacks by shipworm, the structural materials used for culture need to be replaced after three harvests. Therefore, in calculating cost/benefit per harvest, we assumed a write-off period of three harvests. Harvest, including the restocking of four culture units, takes one day of labour assistance (in addition to the farmer's own time) and stockings seeded with 50 spat, uniformly cost IDR 1,000 per stocking. Filling a stocking with 50 seed mussels was much less labour-intensive than the conventional method of stocking metre-long culture ropes with a kilogram or more of mussel seed (Mohamed, 2015). Harvest was after 2–3 months when mussel shell length was 3–5 cm, and the mussels were ready for sale to the middleman for IDR 5,000/kg.

Table 1 shows the costs and revenues generated for a farmer using a production unit of 80 stockings (80 stakes with stockings and 16 longlines with 5 stockings each). The calculations were based on the above cost inputs and the production figures from our experiments.

Slightly lower costs for set-up in terms of both material, labour assistance and time invested, as well as higher production levels with longline culture, combined to make the income generated from rope culture almost twice as high as for stick culture (Table 1). The average return for farmers (from an 80-stocking culture) using the stake method was 69,552 IDR per day of own time invested, whereas by using the longline method the return was 128,636 IDR per day. The estimated profitability of mussel culture using the stake method was below the average hourly wage for skilled labour, whereas using the longline method yielded an average return above the daily wage rate for skilled labour.

4 | DISCUSSION

In our experiments, spat was collected more abundantly but also with greater variability by longline (6,786 ± 3,476 ind.m^{-2}) than by stake (2,412 ± 484 ind.m^{-2}). Spat settlement onto artificial surfaces is highly dependent on shape and structure (Karayücel et al., 2009). Hence, generalizations across areas, species and differing

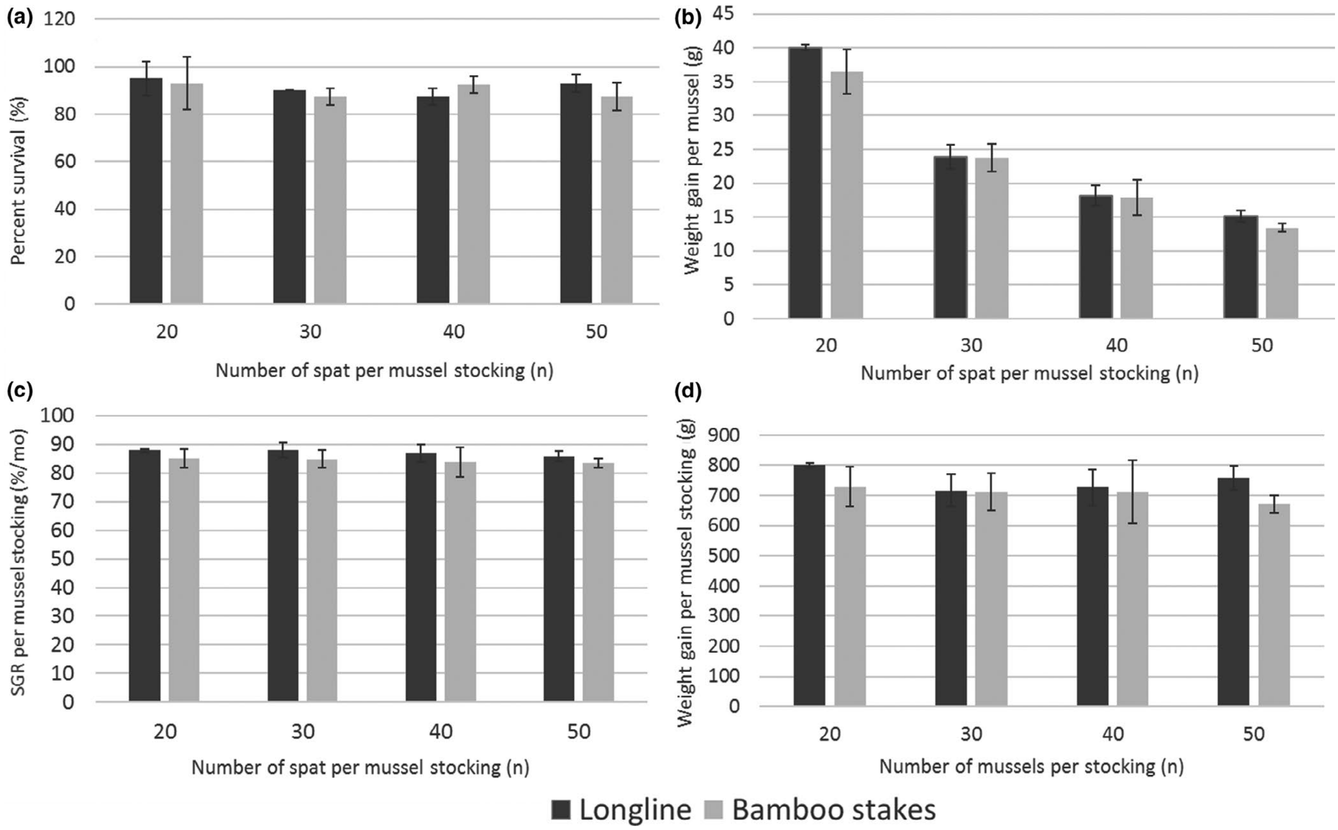

FIGURE 4 Comparison of measurements on mussels grown in stockings at different initial stocking densities on longlines and on bamboo stakes ($N = 6$; ± 1 *SD*). (a) Average % survival of mussels. (b) Average weight gain of individual mussels. (c) Monthly specific rate of weight increase (SGR) per mussel stocking (%/mo). (d) Average weight gain (G) per stocking during grow-out

environmental conditions are difficult. Settlement densities obtained for the Mediterranean mussel (*Mytilus galloprovincialis*) in the Black Sea were 3,450 ± 126 ind.m^{-2} (Karayücel et al., 2009). In India, where mussel culture has grown rapidly in recent years (Mohamed, 2015), the practice is based on natural spat fall on intertidal rocks which is then collected as seed. Kuriakose et al. (1988) indicate typical spat densities of 6,225 ind.m^{-2} on such natural intertidal rock in India. Therefore, our results indicate clearly suitable spat settlement densities for the establishment of mussel culture in Demak. Our site had relatively high current velocities which may influence settlement success in this species (Soon & Ransangan, 2015). In our case, we also found that spat collection was significantly higher with spat collector ropes suspended from longlines than when suspended from stakes. We speculate that the greater level of movement and water exposure might be the reason why collector ropes were more effective when hung from longlines.

Our results also indicate higher growth rates and resulting weight yields for mussels grown in longline culture compared with mussels grown in stake culture. The only difference in culture conditions between the two methods was that the mussels grew in stockings attached to a stationary support with stake culture, while with longline culture they grew in a stocking that can move and turn with water currents, wind and wave action. Mussel growth obtained from the experiment was 24.3 g and 22.9 g for 75 days (2.5 months) of cultivation, respectively, for longlines and stakes. Therefore, average weight increments per mussel were 9.72 g.month^{-1} and 9.16 g.month^{-1} respectively. These results were significantly higher than the mussel growth rates documented by Karayücel et al. (2010) (6.38 g.month^{-1}), Kuriakose et al. (1988) (5.8 g.month^{-1}) and in raft culture farther from shore elsewhere in Indonesia (Noor et al., 2019). We conclude that the area selected was very suitable for mussel growth which made harvest in only 2.5 months possible. The increased movement of the mussel stockings in the longline method may reduce fouling, build-up of sediment and possibly also improve access to planktonic food compared with the stake method, thereby allowing higher mussel growth rates and higher weight yields. Further work is needed to identify the exact causes for the documented higher productivity of longline versus stake culture. Density of mussel stocking numbers did have a significant effect on the growth but not on survival rate of individual mussels. It is common that higher stocking density leads to both lower average body weight and lower survival rate (e.g. Karayücel et al., 2015). However, in our study we did not observe lower survival rates. We speculate that general growth conditions under all examined stocking densities were so favourable that the mussels were not affected strongly enough to influence their survival. The differences in stocking density (20–50 mussels per stocking) did result in different growth rates for individual mussels but not in the total weight yield achieved by the mussel stockings. Low stocking density simply yielded fewer larger mussels, while higher stocking densities yielded more but smaller mussels for a similar

TABLE 1 Cost-benefit analysis (in Indonesian Rupiahs, IDR) generated with green mussel (*Perna viridis*) cultivation on bamboo stakes and longlines based on 80 stockings with initial seeding densities of 50 spat per stocking

Cost and revenue components	Bamboo stake culture (80 stockings)	Longline culture (80 stocking units)
Set-up costs (IDR)		
Stakes	186,640	74,656
Rope	40,000	136,000
Assistant for set-up	100,000	50,000
Total set-up costs	326,640	260,656
Set-up costs per harvest (write-off over 3 harvests)	108,880	86,885
Other costs per harvest		
Spat stockings	80,000	80,000
Assistant for harvest	50,000	50,000
Total costs (TC) per harvest (IDR)	238,880	216,885
Yield per stocking		
Initial stocking weight (kg)	0.215	0.215
Average weight increment	0.672	0.759
Harvest weight (per stocking)	0.887	0.971
Harvest from 80 stockings (kg)	70.96	77.68
Selling price (IDR/kg)	5,000	5,000
Total revenue (TR) per harvest (IDR)	354,800	388,400
TR-TC (IDR)	115,920	171,515
Farmer time invested		
Time for set-up (d)	2	1
Set-up time per harvest (write-off in 3 harvests)	0.67	0.33
Time for harvest (d)	1	1
Total farmer time investment per harvest (d)	1.67	1.33
Farmer income per day invested (IDR/d)	69,552	128,636

total weight yield. This makes us believe that it was not the filtering capacity of the mussels that ultimately limited weight yield but the total amount of water that the mussels were effectively exposed to. This should be a combined function of water flow, stocking size and shape, and any possible constraints caused, for example, by the use of the small-meshed stockings. It should be noted that the technique used for grow-out (mussels retained in small-mesh bag) was different than typical methods used in South-East Asia and India (stake or rope) where mussels are stocked at higher density and may have more direct access to the food flux. Yield at the higher densities tested would probably be higher with the latter methods.

The most recent review on the status of mangroves worldwide concluded that integrating human livelihood needs in mangrove conservation is necessary to achieve long-term sustainability for mangrove forests (Romañach et al., 2018). A major challenge to mangrove restoration initiatives such as those in Demak is that, lacking mangrove-friendly livelihood alternatives, local farmers tend to simply cut down newly restored mangrove stands in order to re-excavate former ponds for shrimp culture. In doing so, they perpetuate their unsustainable livelihood practices and ultimately render mangrove restoration unsuccessful in the long run. This means that there is a great need to develop viable yet mangrove-compatible livelihood alternatives for communities inhabiting mangrove areas. Such alternatives may include livelihoods based on mangrove-supported fisheries, ecotourism or a multitude of other sustainable uses of mangrove products and resources. Unfortunately, very few of these alternatives have yet been developed beyond a purely artisanal level and the need for mangrove livelihood innovation and development has been stressed by several authors (Datta et al., 2011; Kusmana, 2018; Tamrin et al., 2018).

Our results show that mussel culture using longlines for both spat collection and grow-out at densities of 50 mussel seeds per stocking is a simple, low-cost and easily adopted source of income for households in areas where other means of income generation have been lost or are limited. Culture of the species in other countries in the region has proven profitable and has developed into important sources of income and food for coastal communities (bin Sallih, 2005; Mohamed, 2015). As an aquaculture practice, longlines are a mangrove-friendly alternative livelihood as it does not require mangroves to be removed for pond construction. They can be placed alongside mangrove channels, in lagoons, inside abandoned ponds and in shallow marine areas seawards from the mangrove forests without any need to cut mangroves or excavate ponds. In fact, longline culture is even considered ideal for unprotected open-sea culture conditions (Mohamed, 2015). This means that mussel culture can serve as an economic incentive to preserve mangroves so the latter can be left intact to fulfil their many other important ecosystem functions (Romañach et al., 2018). Mussel culture seems to be a fully gender-compatible source of supplemental income in poor coastal communities on Java such as observed elsewhere (Kripa & Surendranathan, 2008; Mohamed, 2015; Rajagopal et al., 2006; Tan & Ransangan, 2016; Vipinkumar et al., 2015).

Environmental contamination is known to be a problem for shellfish in heavily populated areas along the north coast of Java (Cordova et al., 2012). For Semarang and the area of concern, the situation is less clear, but at least two studies suggest that contamination levels are low enough for safe consumption (Suprapti et al., 2014, 2016). However, even though the coastal area of Demak is still largely rural and probably less-contaminated, the issue of contamination deserves close attention.

Longlines present a feasible, more sustainable and more profitable alternative to stake mussel culture for mussel farmers in the Demak region in Central Java. Innovation towards a more significant mussel culture industry in Indonesia is long overdue and we are convinced that additional research towards methods of scaling up production, improved site selection and greater efficiency in the market value chain (e.g. bin Sallih, 2005) could further improve green mussel culture profitability, and thereby make it even more effective as a mangrove-friendly alternative livelihood option for the inhabitants of economically strained coastal communities.

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CONFLICTS OF INTEREST

The authors have no conflicts of interest to declare.

ORCID

Adolphe O. Debrot https://orcid.org/0000-0001-9406-8150

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