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RESEARCH ARTICLE

Dredging-induced shell damages to hard clam (*Meretrix meretrix*): a Malaysian case study

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Abstract – The hard clam (*Meretrix meretrix*) is a popular edible shellfish in South and Southeast Asia, being heavily exploited by hand dredging in Marudu Bay, Malaysia. The current study was performed to evaluate the shell damages caused by this artisanal dredging gear. Samplings were conducted in triplicates at two sites using both hand dredging and hand collecting (control) sampling methods. The shell length and total weight, damage areas and breakage patterns of each clam were recorded. A questionnaire survey was conducted with local bivalve harvesters to gather information on the fishing pressure in Marudu Bay. Results revealed that the efficiency (fishing yield) of hand dredging gear was three times higher than hand collecting. However, hand dredging gear causes lethal shell damages to small hard clams (<3cm in shell length). Hard clam harvesting is the main occupation of most fishermen in Kg. Popok, but most of them do not comply with the minimum harvesting size established by the fishery department. Moreover, most of the stakeholders are not aware of the negative impacts of hand dredging to the sustainability of the hard clam fishery in Marudu Bay. Therefore, organizing more awareness programs combined with introducing community-based fishery management are highly recommended to promote the sustainability of this artisanal fishery.

Keywords: Hand dredging / fishing impacts / shell damages / ecological impact / Marudu Bay / Malaysia

1 Introduction

The hard clam, *Meretrix meretrix* (Linnaeus, 1757), is a commercially important species in coastal areas of South and Southeast Asia (Liu et al., 2006). In Sabah (Malaysia), hard clam fishery is an important industry that supports the livelihood of coastal community in Marudu Bay (Tan et al., 2017). According to an elderly in Kg. Popok (fishermen village at bay pocket of Marudu Bay, Malaysia) in an interview survey, a traditional fishing gear locally known as *tumbak* was initially used to collect hard clams in Marudu bay in early 1960. Hard clams are located by poking the narrow end of the tool into sediment. The upper sediment layer is removed to collect hard clam once hard objects are detected (Peterson, 2002). The average catch by using *tumbak* fishing gear was 3–4 kg/harvester/h. Hand dredging gear was introduced from Philippine in early 1980 to Tanah Merah, west coast of Marudu Bay. This harvesting technique was then introduced to Kg. Popok in 2004. The average catch of hard clams by using hand dredging was 30–40 kg/harvester/h, whereas the highest catch was record in 2007 with 80–90 kg of hard clam/harvester/h. Unfortunately, the catch of hard clams was decreased gradually since 2013 to about 5 kg of hard clam/harvester/h, while the native communities suspected the growing palm tree agriculture around the bay was responsible for the decreasing hard clam population in Marudu Bay. It is interesting to note that not only the number of hard clams was reduced but the average size of hard clam also became smaller.

A preliminary study was conducted in early 2017 to evaluate the fishing pressure over hard clam in Marudu Bay. Finding suggested that the hand dredging fishery in Marudu Bay negatively affected the population of hard clam and threatened the biodiversity of non-target species by causing significant levels of shell damage (Tan et al., 2017). Several studies have been performed to assess the impact of dredges on bycatch and macrobenthic communities (Vasconcelos et al., 2011; Gaspar and Chicharo, 2007), and the deleterious impact of bottom dredges on the benthic environment has been extensively documented worldwide (Carbines et al., 2004). Generally, the damage of hydraulic blade dredge to the bivalves varies depending on shell thickness and burrowing depth. Large, relatively thin-shelled bivalves such as *Ensis arcuatus* and *Lutraria angustior* are often broken, while the more compact species such as *Dosinia exoleta* and *Clausinella fasciata* remain intact (Hauton et al., 2003).

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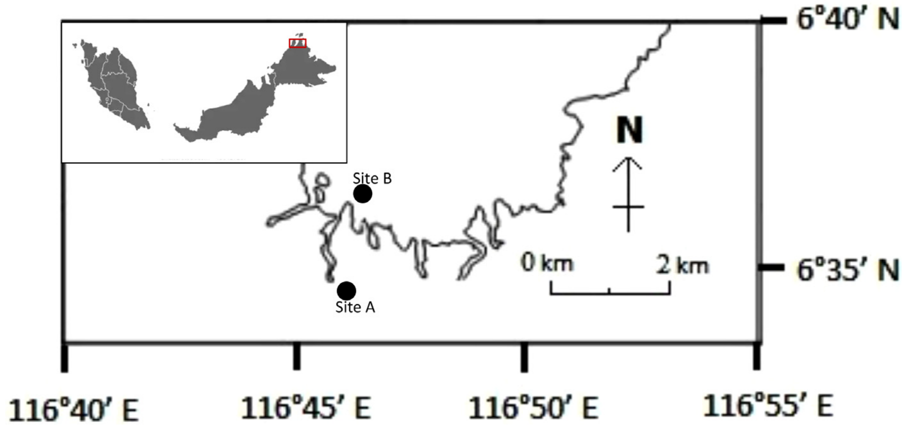

Fig. 1. Location of the sampling stations for harvesting the hard clam, *Meretrix meretrix* in Marudu Bay, Malaysia.

Most recent efforts to understand the impact of dredges have focused on deep water fisheries. Little is known about the impact of dredges in the coastal environment. Therefore, the ongoing harm to non-target species and damage to marine ecosystems caused by hand dredging is currently an issue of great concern. In this context, the present study aimed to evaluate the fishing damages caused by hand dredging in the Marudu Bay hard clam fishery.

2 Materials and methods

2.1 Study area

Marudu Bay (6°35' to 7° N and 116°45' to 117° E) is located within the Tun Mustapha Park, the largest marine-protected area in Southeast Asia, and part of the Malaysian region of the Coral Triangle Initiative (Tan and Ransangan, 2015). Two sampling stations (Fig. 1) were established in the main fishing grounds of the native coastal community, where local clam harvesters operate daily during low tide.

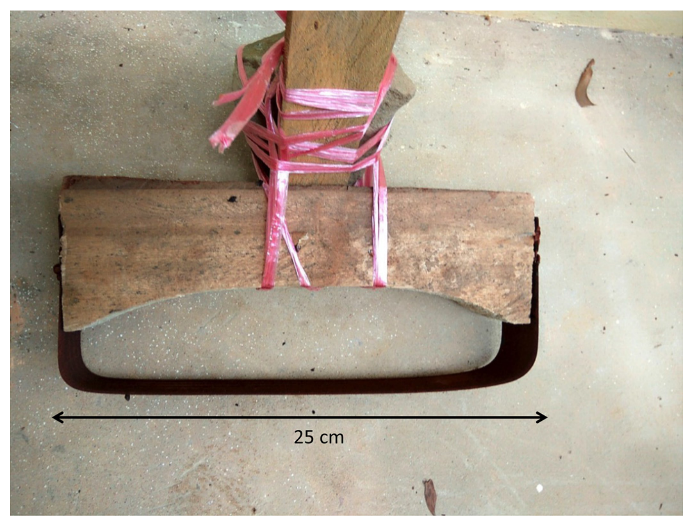

Fig. 2. The artisanal hand dredge “kerek” with blade measurement of 25 × 5 cm^2 and a penetration below sand surface of about 15 cm.

2.2 Sampling

Samplings in triplicates were conducted from February to April 2017 with the help of a local fisherman during low tide according to Gaza et al. (2014). Bivalve samples were caught from an area of 500 m^2 (50 m × 10 m) using a hand dredge locally known as *kerek* with blade measurement of 25 cm × 5 cm and a penetration below sand surface of about 15 cm (Fig. 2). For control, samplings in triplicate were conducted by the same fisherman at the two same sites. Bivalves buried 15 cm below surface were discovered by foot, and then the surface sediment was removed to collect the bivalves by hand. The specimens were then placed in labelled plastic bags, and then transported to the laboratory for analysis within 48 h. In the laboratory, samples were sorted and washed to remove all adhering organisms and other debris.

2.3 Bivalve identification and measurement

All hard clams were counted and measured. Individual specimens were measured for shell length (maximum dimension of the anterior–posterior axis) with a Vernier caliper to the nearest 0.1 mm and weighed for total weight on a digital balance. Some representative specimens were preserved in 70% alcohol to further confirm the identification in the Borneo Marine Research Institute laboratory according to Skoglund (1992).

2.4 Shell damage areas and breakage patterns

A total number of 109 and 405 clams were collected by hand collecting and hand dredging, respectively. The shell damage areas and breakage patterns caused by dredging impact were assessed according to Vasconcelos et al. (2011). Valves of each clam were subdivided into four areas according to the shell's main axes, anterior dorsal (AD), posterior dorsal (PD), anterior ventral (AV) and posterior ventral (PV). Four damage scores were assigned based on the following breakage patterns: (1) shell lightly scratched, (2) deep scratch mark on shell, (3) shell cracked and still intact, (4) shell cracked and

Section A

1) Gender

M	F

2) Age (Years)

<17	17-21	22-30	31-40	41-50	51-60	>60

3) Occupation

Bivalve fisherman	Other fisherman	Other

4) Number of family members per household

Section B (If the respondent is a bivalve fisherman)

5) Frequency of harvesting hard clam (days per week)

<1	1-3	4-5	6-7

6) Number of accompanying hard clam harvesters
7) How many hours do you spend collecting hard clams?
8) What is the minimum size of the collected bivalves?
9) What do you do with those clams below marketable size?

Release	Self-consumption	Sell to neighbours

10) How many kilograms are usually obtained per trip?
11) Where do you sell your catch?

Local wet market	Middle man	Neighbour	Self consumption

12) What do you think about the current hard clam fishery to the sustainability of the resource?

Very good	good	Reasonable	Bad	Very bad

13) What do you think about the impact of hand dredging to the sustainability of the hard clam resource?

Great harm	Little harm	No harm

14) How is the clam stock variation over your collection time?

Increase rapidly	increase	same	decrease	Decrease rapidly

15) Why do you think so?

Increase of collectors	Overexploitation	Environmental condition	Other

Fig. 3. Questionnaire on hard clam exploitation at Marudu Bay.

detached. The position of shell damage and the breakage patterns in each bivalve were recorded.

2.5 Questionnaire survey

To collect additional supporting information, a questionnaire survey was conducted at Kg. Popok. The questionnaire was adapted and modified from Mugabe (2016) (Fig. 3). Twenty questionnaires were answered by local clam harvesters (estimated total number of harvesters is 20–25 harvesters) with the help of undergraduate students who provided assistance due to the illiteracy of most respondents. A short explanation was given to each respondent about the aim of the study prior to the interview survey.

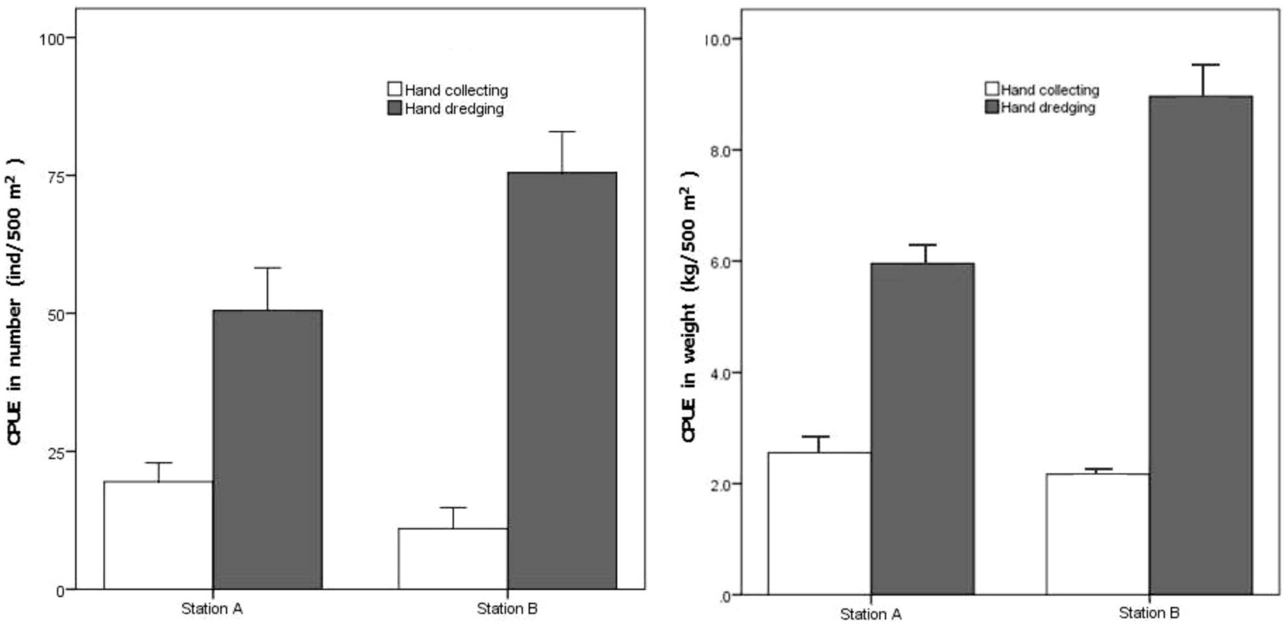

Fig. 4. Fishing yield (CPUE's in number and weight) of the hard clams caught by hand collecting and hand dredging.

2.6 Data treatment and statistical analyses

Statistical analyses were performed using the SPSS Windows Statistical Package (version 21). Tests were considered significant at $p < 0.05$. Prior to analyses, all variables were tested for normality and homogeneity of variances. Independent *T*-test was used to test for significant differences between sampling methods for number and weight of harvested clams, and percentage of shell damages.

3 Results

3.1 Catches and harvesting yield

Average number and total weight of hard clams collected by hand collecting (control) and hand dredging in sites A and B are presented in Figure 4. The average number and total weight of hard clams collected using hand dredging (number = 132 ± 29.93; total weight = 15.55 kg) were significantly higher (t(486) = 3.55, $p < 0.05$) than those collected by hand harvesting (number = 30.3 ± 9.8; total weight = 5.26 kg).

Histograms of the size distribution of the hard clams caught by both hand collecting (mean ± SD = 4.7 ± 1.2 cm, range = 2.1–8.1 cm) and hand dredging (mean ± SD = 4.6 ± 1.3 cm, range = 1.8–10.4 cm) are illustrated in Figure 5. The mean shell length of hard clams collected by hand was significantly larger (t(486) = 2.5, $p < 0.05$) than those collected by hand dredging. The proportions of individuals caught below the minimum landing size of 5 cm in shell length was almost double in hand dredging (69.5%) compared to hand collected sampling method (38.5%).

3.2 Frequency and degree of shell damage

The degree of damage caused by hand collecting and by the dredging gear to hard clams is illustrated in Table 1 and Figure 6. In general, intact hard clams were significantly less (t(175) = 3.45, $p < 0.05$) in specimens collected by dredging gear (26.2%) than by hand collecting (79.3%). The percentage of hard clams with lethal shell damages (deep scratch or cracked shell) was significantly higher ($p < 0.05$) in specimens collected using dredging gear (21.9%) compared to hand collecting (4.4%).

The proportions of damaged to undamaged shells below and above minimum landing size were 0.36 and 0.23 for hand collecting and 4.23 and 2.15 for hand dredging. The frequency of shells lightly scratched on the dorsal part was significantly higher (t(89) = 2.33, $p < 0.05$) in larger hard clams (>7 cm), whereas lightly scratched shells at ventral part was higher in smaller hard clams (3–5 cm). On the other hand, the frequency of deeply scratched shells at both dorsal and ventral parts was higher in smaller hard clams (<5 cm). Lethal damage (shell cracked) was only observed in specimens collected by hand dredging with the highest rate in hard clams smaller than 3 cm (4.5%), followed by 3–5 cm size class (1.1%) and by the 5–7 cm size class (0.4%).

3.3 Questionnaire survey

Based on the questionnaire survey, 53.8% of the fishermen in Kg. Popok are bivalve harvesters. Most of them (61.5%) are male and their average age ranges between 31 and 40 years. They have 4–10 family members per household with a mean of 6.4 family members per household. Bivalve fishermen spend 6–7 days per week targeting hard clams, where they usually harvest in a group of seven people and spend 7 h at sea (including about 2 h in transportation). When hard clams below marketable size (<5cm) are caught, only 28.5% of the harvesters release them back to the field, whereas the remaining (71.5%) keep them for self-consumption or for selling to neighbours at lower price. The average daily catch is

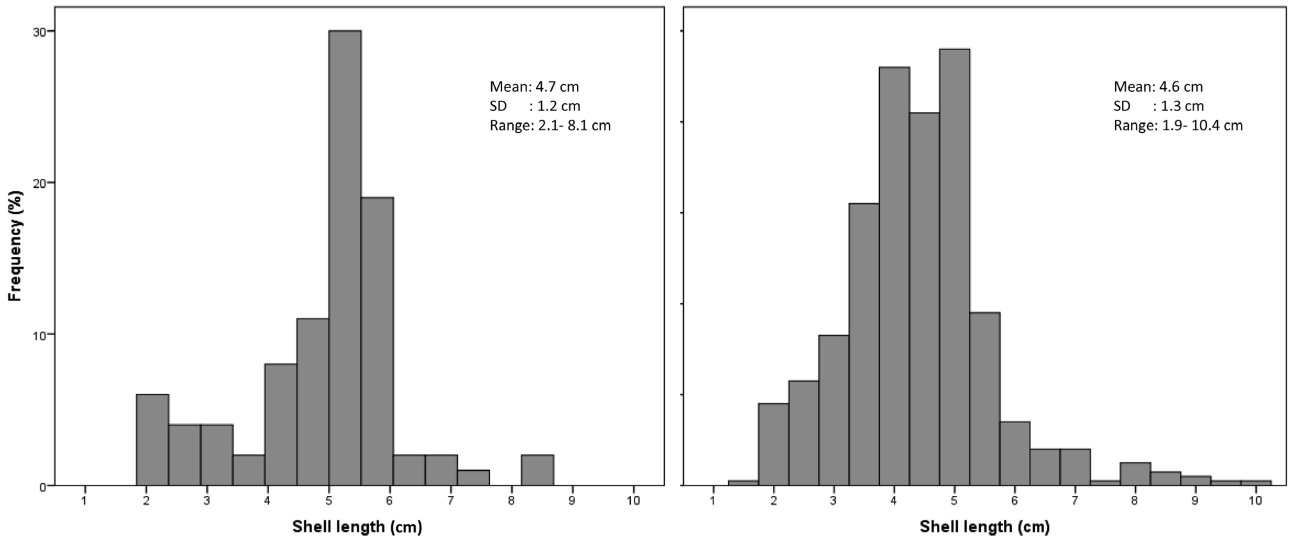

Fig. 5. Size frequency distribution of the hard clams caught by hand collecting ($n = 109$) (left) and hand dredging ($n = 405$) (right).

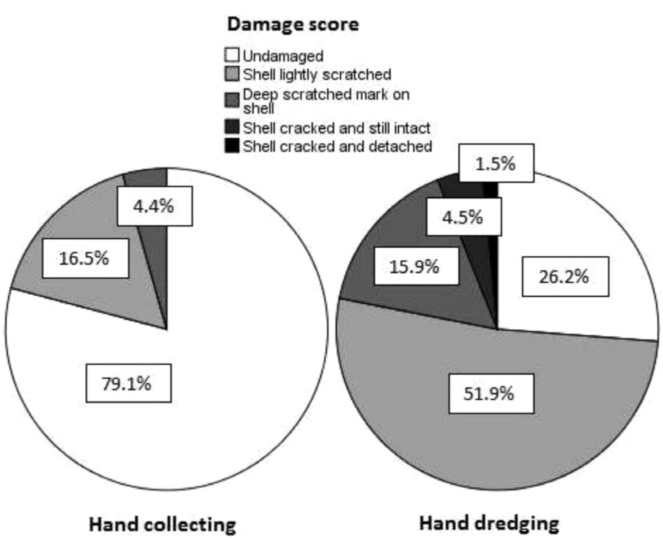

Fig. 6. Shell damage frequency and degree inflicted to the hard clams caught by hand collecting ($n = 109$) and hand dredging ($n = 405$).

5.9 kg/harvester. The catch is sold at town market (43%), by middlemen (28.5%) and in the neighbourhood (28.5%). All respondents are aware that the hard clam stock is depleted, but very few (7.7%) believe that depletion is due to overfishing or to the fact that current harvesting method using hand dredges gear is destructive to the fishing resources. Most respondents (61.5%) believe that palm tree plantation around the bay is responsible for the decline of hard clam population in Marudu bay.

4 Discussion

Hand collecting is a traditional and common clam harvesting technique (Peterson, 2002; Leblanc et al., 2005). Hand collecting poses minimum negative impacts to the harvested clam and their environment (Peterson, 2002). However, as shown in the current study, this harvesting technique has much lower efficiency compared to hand dredging (30 and 132 for hand collecting and hand dredging, respectively). The most significant advantage of hand dredging is discovering the deep borrowing largest clams (>8 cm), which are not usually collected by hand collecting. Larger clams are known to have the ability to dig and hide in deeper sediments (Bergonci and Thome, 2008); therefore, searching hard clams using foot could push them into deeper sediments and greatly reduce the encounter rate of larger clams by hand collecting. The higher fishing efficiency of hand dredging compared to hand collecting is further supported in the current study by the wider size range (higher SD) of hard clams caught by this harvesting method.

The current study also showed that the proportion of individuals caught below the minimum landing size was double in hand dredging compared to hand collecting. This means that hand dredging could induce deleterious effects to hard clam populations by decreasing the number of juvenile clams. On the other hand, the proportions of damaged to undamaged shells in hand dredging were about 10 times higher than those in hand collecting for both hard clams below (4.2 versus 0.4) and above (2.2 versus 0.2) the minimal landing size. Dredging fishery is a destructive technique that causes expectable damages during the fishing operations (Tan et al., 2017).

Shell damage areas and breakage patterns in the hard clams are size dependent. This also suggested the damage of dredging gear to the bivalves varied depending on shell thickness and burrowing depth (Hauton et al., 2003). For non-lethal shell damages, larger clams showed higher frequency of shells lightly scratched on the dorsal part, whereas smaller hard clams showed higher frequency of shells lightly scratched on the ventral part. Bivalve burying depth has been reported to be directly proportional to shell length (Bergonci and Thome, 2008). This fact supports the current finding that larger clams with deeper burying ability have higher probability of being scratched at the dorsal part by the hand dredge. On the contrary, smaller clams that inhabit at shallower sediments are

Table 1. Influence of specimen size (hard clam shell length subdivided into four size classes) on the damage frequency and degree inflicted by hand collecting and hand dredging.

		Hand collecting					Hand dredging				
	Shell length	0	1	2	3	4	0	1	2	3	4
Dorsal	<3cm	–	–	–	–	–	–	–	–	–	–
	3–5cm	–	–	4.3	–	–	–	5.7	5.4	–	–
	5–7cm	–	3.2	0.1	–	–	–	6.8	4.1	–	–
	>7	–	7.2	–	–	–	–	17.8	–	–	–
Ventral	<3cm	–	–	–	–	–	–	–	3.5	–	–
	3–5cm	–	3.2	–	–	–	–	10.5	1.6	–	–
	5–7cm	–	2.8	–	–	–	–	5.6	0.3	–	–
	>7	–	–	–	–	–	–	1.6	–	–	–
Both dorsa	<3cm	5.1	–	–	–	–	1.1	–	0.7	3.4	1.1
	3–5cm	15.4	–	–	–	–	7.3	2.5	0.3	0.7	0.4
	5–7cm	38.7	–	–	–	–	7.0	1.4	–	0.4	–
	>7	19.9	–	–	–	–	10.2	–	–	–	–
		79.1	16.4	4.4	–	–	25.6	51.9	15.9	4.5	1.5

Notes: 0–undamaged; 1–lightly scratched; 2–deeply scratched; 3–cracked but still intact; 4–cracked and detached from shell.

more likely of being impacted at the ventral part of shell by the hand dredge. Fortunately, non-lethal shell damages with minimal impacts on the population are not an issue of great concern, since bivalve have the ability to repair their shells (Schejter and Bremec, 2007).

However, special attention must be given to those hard clams that suffer significant shell damage and with lower likelihood to survive after fishing operations. The current study recorded high proportion (21.9%) of hard clams caught by hand dredging with lethal shell damage. Similar observations have been reported elsewhere, with significant proportions of target species caught or left on the dredge path with damaged shells, which cause indirect fishing mortality (Gaspar et al., 1998; Moschino et al., 2003). The degree of shell damages caused by hand dredging is also size dependent. The present study did not find any evidence of hand dredging causing lethal damage to large clams (>7 cm in shell length). The shell thickness and strength of *M. meretrix* is known to increase with increasing shell length (Indraswari et al., 2014), thus explaining why large clams (>7 cm in shell length) are strong enough to withstand the impacts by hand dredging. However, high percentage of deep scratches and shell breakages were recorded in smaller clams (<5 cm), showing that hand dredging could induce high indirect fishing mortality of commercially undersized hard clams, although they are not the target catch in this fishery.

Minimum harvesting size is broadly applied in bivalve fishery management (Branch and Clark, 2006; Van Wynsberge et al., 2013). In Marudu Bay, the minimum harvesting size approach has also been implemented, but most clam harvesters do not comply this management measure established by the local fishery department. This reveals that not all stakeholders are informed and aware of the impact of harvesting juvenile individuals to the sustainable of hard clam population. Rising awareness is therefore a crucial component, namely, by informing the measure required to promote a sustainable fishing activity (Bates, 2010). In addition, the current study suggests that the minimum harvesting size alone is insufficient to ensure the sustainability of hard clam fishery in Marudu Bay, because high mortality occurs in commercially undersized individuals during hand dredging fishing operation. Since hand dredging only caused lethal damages to small clams, this harvesting technique should be banned from the nursery ground of hard clam. Juvenile clams are generally concentrated on the sandy substrates rather than on the muddy substrates (Nair et al., 1984; Rankin et al., 1994; Bergonci and Thome, 2008), thus hand dredging should be prohibited in upstream. In this context, a detailed study on spat settlement sites of hard clam in Marudu Bay is highly recommended to provide more information for promoting a sustainable bivalve fishery management plan.

The introduction of hand dredging in Marudu Bay bivalve fishery has increased the catch and consequently the income of clam harvesters. Since then, bivalve harvesters became the main occupation of coastal community in Kg. Popok, where they go fishing every day in a group. The intensified clam harvesting in shoreline areas that also constitute potential nursery grounds for the hard clam could be responsible for decreasing the hard clam population in Marudu Bay. In fact, excessive shellfish harvesting has been documented to affect the population structure of marine bivalves and altered near shore coastal ecosystems (Rick and Erlandson 2009). Moreover, decrease in biodiversity after dredging that persist over long periods of time has been reported (Constantino et al., 2009).

Intensive palm tree agriculture surrounding the Marudu Bay had been blamed as the causative factor of the declining hard clam population in Marudu Bay. However, recently published studies revealed that the level of heavy metal pollution (Tan et al., 2016; Denil et al., 2017), nutrient pollution (Tan and Ransangan, 2016a, b, d, 2017) and potential harmful algal (Tan and Ransangan, 2016c) in the water and sediment of Marudu Bay is far below the level that could threaten the hard clam. Nevertheless, we do not rule out the possibility, with high sedimentation rate due to sediment runoff from palm plantations during heavy precipitation, which could clog hard clams' gills and negatively affect their population in Marudu Bay.

The current study confirmed that the hard clam fishery is important to the livelihood of the coastal community in the Marudu Bay. Hand dredging is an effective fishing tool that allows higher catches and also provides better income for fishermen. However, hand dredging causes lethal shell damage to the juvenile hard clams, which affects the overall hard clam population by increasing the bycatch mortality (due to shell damage induced in commercially undersized individuals). This situation is worsening when some stakeholders violate the minimum harvesting size. To address this issue, community-based fishery management is highly recommended, combined with organizing more awareness rising programs to promote a sustainable bivalve fishery in Marudu Bay. In addition, further studies are required to identify nursery grounds of hard clams, where hand dredging should be prohibited.

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