Abalone culture and farming in Tun Sakaran Marine Park, Sabah

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Summary

1. INTRODUCTION

1.1. The need for alternative livelihoods in Tun Sakaran Marine Park (TSMP)

Key objectives for TSMP as outlined in the Management Plan (Wood *et al*., 2001) are to:

- Protect, maintain and enhance biodiversity and the health of the environment.
- Maximise opportunities for economic development and ecologically sustainable use of the area and its resources.
- Ensure local people are involved in, and benefit from the creation of the Park.

One of the main challenges in achieving these objectives is to deal with the legacy of decades of heavy exploitation of marine resources. Fishing (including destructive fishing) and gleaning in the area that is now within the 350km^2 Marine Park has caused stocks of reef fish and other edible species to fall to very low levels. This has not only had a negative impact on biodiversity, but is causing hardship to local communities because of increasingly low catches.

In order to achieve the management objectives for the Park, fishing needs to be managed and fishing pressure reduced so that stocks can recover. Implementing measures to reduce fishing effort will inevitably have an impact on communities that currently rely on fishing to make a living, at least in the short term. For this reason it is important to focus alternative or supplementary livelihood programmes towards these communities in order to avoid social upheaval and economic hardship.

The fishing community in TSMP comprises the fishers themselves, their families and those who trade in fishery resources. The 2006 Community Census revealed that fishing was the main occupation of approximately 30% of households in the Park. Virtually all of these households were from the Bajau Laut ethnic group which in 2006 amounted to 114 households (Wood *et al*., 2007). There has been some movement within and in and out of the Park since that time, but it does not appear that there have been significant long-term changes in the number of Bajau Laut households.

Although the full-time fishers are nearly all from the Bajau Laut community, the fishery itself is driven mainly by around 6-10 dealers (middlemen) in marine resources who buy from the fishermen and then sell the catch in Semporna or further afield. Investigations carried out in 2010 revealed that a few of the dealers are based on the mainland, but most live in the Park. The Bajau Laut and to some extent other ethnic groups within the Park also fish to provide food for direct household consumption rather than sale.

The focus for the alternative livelihood programme in the Park therefore needs either to be directly with the Bajau Laut and/or fish dealers or with other communities who might open up job opportunities for the fishing community.

1.2. Livelihood possibilities for the fishing community

Informal discussions, focus group meetings and workshops about livelihood needs and prospects have been held with communities in TSMP by the Semporna Islands Project and Sabah Parks. These revealed positive attitudes towards alternative or supplementary livelihoods and a number of possibilities that could be explored.

Tourism development in the Park is opening up a number of livelihood opportunities, ranging from 'Homestays' to nature, wildlife and dive guiding, running cafes or gift shops and selling handicrafts. A small Homestay has already opened on Pulau Selakan, run by people from the island. Making and selling of items such as locally-made mats is another possibility. Due to transport costs and competition within the craft sector in Sabah it appears that the best way forward is for craftwork enterprises (especially those involving the Bajau Laut) to be 'homebased', with direct sales to visitors to the Park, rather than merchandising through tourist and craft shops (Wood *et al.*, 2011).

Other job opportunities lie in low-impact mariculture, such as farming of seaweed and marine invertebrates. Such ventures are particularly appropriate for fishing communities because this sector are familiar with working in the marine environment.

Seaweed farming has been established in the Semporna area for decades and the local community has expressed considerable interest in diversifying into culture and farming of other marine species, including various invertebrates. Giant clams, sea-cucumbers and abalone are potential candidates for culture and sea ranching. All of these animals have been over-exploited in the Park, which provides an additional incentive for culture because some of the animals that are reared could be used for stock enhancement.

Giant clams have already been successfully reared at the hatchery in Tun Sakaran Marine Park (photo, right) but economic returns are less good because growth is slow and it takes 5 years or more to reach market size for food. Prices are also relatively low. They are sold fresh in Semporna market for food (flesh only; no shell) for around RM5/kg (c. £1). A more economically attractive proposition is to sell juvenile giant clams live for the aquarium trade. However it would be complicated due to the complexities of live export and the necessity to have CITES permits for each consignment.

Sea-cucumbers have a high market price and are sold locally and for export, mainly dried. However, it is acknowledged that culture and rearing of these animals can be challenging. Abalone also fetch high prices. In the Semporna area, prices paid to fishermen for the tropical abalone *Haliotis asinina* are around RM 10-12/kg and middlemen sell to traders for RM19-20/kg. This is one of the fastest growing species and can be ready for market in less than a year.

1.3. Concept and principles for abalone farming in TSMP

There are approximately 100 abalone species worldwide of which about 25 are of commercial interest. Of these 25 approximately 16 species are cultivated, including one hybrid. Abalone culture is now practised in many countries including Japan, China, Taiwan, the United States, Mexico, Chile, Australia, New Zealand, Thailand, Korea, France and Ireland among others (Leighton, 2008). *Haliotis asinina*, known as the tropical or 'cocktail' abalone, is one of the species that is cultivated In SE Asia, but as yet there are no abalone farms operating in Malaysia.

Semporna is the main area in Sabah where wild *H asinina* are collected for domestic use and export. The animals live under corals and rocks on shallow reef tops, emerging at night to feed. Harvesting is unregulated and there is no information on population status. The fishery is attractive because of high market prices and it is likely that abalone stocks are being over-exploited, as they are in many other parts of the world.

Haliotis asinina is one of the fastest growing of all the commercial abalone and is generally sold at a relatively small 'cocktail' size. Under ideal growing conditions it can reach a saleable size (50 mm SL, average body weight of 30g) in as little as 180 days (6 months) (Encena *et al*., 2013). This makes it a good candidate for farming.

Abalone farming comprises two main phases: a) spawning and culture of larvae and juveniles under controlled conditions, usually in a land-based facility and b) grow-out of juveniles to market size, typically in the open ocean, where they are maintained until they reach market size.

Currently local communities in Tun Sakaran Marine Park do not have the facilities or financial resources to produce abalone seed. However, a hatchery exists that can fulfil this role. It was built on Pulau Boheydulang by Sabah Parks in the mid-1990s with the intention of breeding marine invertebrates to enhance over-exploited populations and support alternative livelihood initiatives. Furthermore, in 2010 a member of Sabah Parks staff (Jalil Mapait) was trained in the culture of abalone at the Bolinao Marine Laboratory (BML) of the University of the Philippines Marine Science Institute (UP-MSI).

Phase 1 of the abalone farming programme is therefore centred on the Boheydulang hatchery. In Phase 2, local communities farm abalone in ocean cages once the hatchery juveniles have reached a size that is robust enough to be 'planted out'. The aim is for abalone farmers to be provided with juveniles for the start-up phase until enough income is generated for the participants to buy their own juvenile stock for grow-out.

There are several key principles or conditions that need to be met for this programme to be acceptable and successful. In particular the aquaculture programme should:

- Meet appropriate standards to ensure that both culture and grow-out are ecologically sustainable.
- Provide stock for enhancing depleted populations within TSMP.
- Bring measurable improvements to the lives and livelihoods of the local fishing community.

2. Production procedures

2.1. Broodstock

Mature broodstock are required to produce eggs and sperm for the breeding programme. Abalone are dioecious with individuals of separate sexes that live together generally in the ratio of 1 female to 1 male.

2.1.1. Procurement

Semporna is one of the areas in Sabah where the donkey's ear abalone can be widely found. Interviews with fishermen revealed that *H. asinina* occurs on many of the shallow reefs in and around the Tun Sakaran Marine Park. Omadal and Kulapuan both have active abalone fisheries and have supplied broodstock. The buying price from Kulapuan in 2015 (including delivery) was RM 25/kg and a consignment of 10kg provided 128 individuals, many of which were mature.

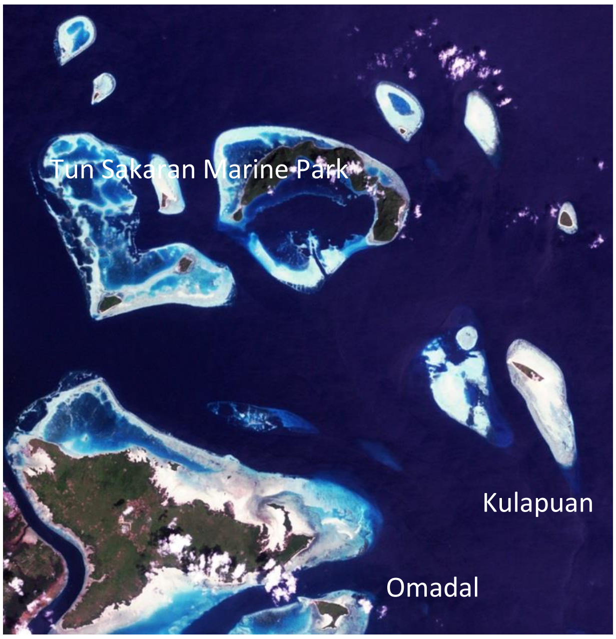

Figure 1. Map of TSMP and surrounding islands showing sources of abalone broodstock.

Figure 2

Freshly collected broodstock

2.1.2. Maintenance of broodstock

Abalone broodstock can be maintained in land-based facilities or in the sea. The most important requirement in order that they are in prime condition for breeding is that they are kept in enclosures with good water circulation, places to shelter and adequate quantities of suitable food.

Both onshore and offshore facilities have been used for the broodstock at Boheydulang. For the onshore facilities, the abalone were kept in baskets floating in concrete raceways with flow through of filtered seawater extracted from the adjacent lagoon. Lengths of PVC piping were placed in the baskets to provide shelter.

The advantage of the onshore system was that the animals could be inspected and fed more easily. However, there are sometimes issues with water quality partly because of the lack of a regular electrical supply to run the pumps and aerate the water. In addition, space in the hatchery is limited.

Two sea net-cages measuring approximately 3m x 3m were constructed and installed in the Boheydulang back reef lagoon adjacent to the hatchery in the deepest part as possible from the land. Sections of PVC piping were placed in the cages to provide shelter.

Figure 3.

Floating cages for abalone broodstock in the Boheydulang lagoon adjacent to the hatchery.

2.1.3. Feeding the broodstock

Either artificial feed (dried pellets of a specific formulation) or natural feed in the form of seaweed are used to sustain abalone. Artificial feed suitable for abalone is not currently available in Sabah and would be expensive to import, whereas suitable species of seaweed grow locally and can be cultivated.
The most widely farmed seaweed in the Semporna area is the red alga *Kappaphycus* sp. (previously known as *Eucheuma*). This is a fairly fleshy, 'tough' seaweed that is grown locally in large quantities for production of agar. It is not on the list of species recommended as a food for abalone, but because of its wide availability it has been purchased from the seaweed farmers and fed to the abalone broodstock.

The softer, finer alga *Gracilaria* is particularly recommended for *H. asinina* and surveys were carried out locally to find a source. *Gracilaria* is not cultivated but sometimes grows as a weed on the seaweed lines. Arrangements were therefore made with one of the seaweed farmers at Selakan to provide *Gracilaria* and similar soft varieties on a weekly basis. It was noted that the abalone took this in preference to *Eucheuma* and steps have now been taken to cultivate *Gracilaria* close to the hatchery so that there is a consistent supply.

Feed is given every day at about 20 % of the body weight of the abalone.

Figure 4. *Gracilaria* (on top) and another fine unidentified red alga sourced from Selakan – both are being used to feed the abalone broodstock.

2.2. Spawning and egg collection

2.2.1. Gonad index

As the time for spawning approaches the gonads become engorged with mature gametes and their colour becomes distinct.

Male and female specimens are easily distinguished. The gonad of the female is either dark green or brownish, while that of the male is either milky-white or yellow.

Figure 5 Mature female abalone showing the dark green coloured gonad.

The condition of the broodstock is recorded as part of the monitoring procedures, in order to check readiness for spawning. Maturity is determined through visual inspection and registration against a Gonad Maturity Index (GMI) as shown in Table 1.

Stage	Description	Male	Female
0	Immature	Gonad not visible; thin and flat. Grey in colour. Comprises 0% of conical appendage	Gonad not visible, thin and flat. Grey in colour. Comprises 0% of conical appendage
1	Early maturation stage	Gonad is thin Pale orange in colour Comprises 20% - 40% of conical appendage	Gonad is thin. Greyish in colour. Comprises 20% - 40% of conical appendage
2	Late maturation stage	Gonad is thick Bright orange in colour. Comprises 50% - 70% of the conical appendage	Gonad is thick, dark green in colour. Comprises 50% - 70% of the conical appendage
3	Mature	Gonad turgid Bright cream in colour. Comprises 80% - 100% of the conical appendage	Gonad turgid Blue or bluish green in colour. Comprises 80% - 100% of the conical appendage
4	Spawned	Gonad appears thin and flabby. Grey in coloUr Comprises less than 20% of the conical appendage	Gonad appears thin and flabby. Grey in colour Comprise less than 20% of the conical appendage.

Table 1. Gonad index for maturity in abalone, based on Singhagraiwan and Doi, 1993 and Capinpin and Hosoya, 1995.

Figure 6. Broodstock census being carried out at the Boheydulang hatchery.

2.2.2. Sexual development and fecundity

Studies into sexual development in *Haliotis asinina* reveal some variation in size and age at maturity. Fermin (2001) reported that under captive conditions, juveniles attain sexual maturity at 35-40 mm standard length (SL) within 8-10 months with males usually becoming sexually mature earlier than females. In Lembok (Indonesia) 50% of the population of *Haliotis asinina* in the area reached first maturity at a shell length of 45 – 50 mm for males and 50 - 55 mm for females (Setyono, 2003).

Setyyono (2003) reported a marked size dimorphism existed between the sexes in *H. asinina* from Lembok. In animals less than or up to 50 mm SL, males had longer mean shell length and higher mean body weight than females. However, in animals greater than 50 mm SL, females had longer mean shell length and larger body weight than males.

In contrast to the studies above, research carried out in Sulawesi (Indonesia) indicated that male abalone did not reach the beginning of gonad maturity until a shell length of 64.50 mm, while female abalone reached it at shell length of 64.09 mm (Hadijah *et al*., 2013).

The broodstock obtained from Kulapuan was a random catch provided by the fishermen and consisted of females between the size of 45 – 80 mm (average 63mm) and males between 45 - 82 mm (average 66mm). The samples did not include a balanced proportion of small to large individuals and so it was not possible to calculate the size at which 50% of the population was mature. However it is relevant to note that several females were at a late stage of maturation at a length of 45mm. This indicates that sexual development is fast in the Semporna area, with maturity reached before the animals are one year old.

	% of individuals	
Gonad maturity	Male	Female
Excellent	12	27
Good/normal	21	33
Not fully mature	67	40

Table 2. Details of 68 male and 75 female abalone sourced from Kulapuan.

Like other abalone species, *Haliotis asinina* is relatively fecund. Fermin (2001) reported that 50 mm females (weighing approximately 25 gm) produce as many as 250,000-300,000 eggs per spawning and that fecundity increases with increasing animal size. According to Singhagraiwan and Doi, (1992) animals in the size range 58-80 mm produced between 200,000-600,000 eggs in a single spawning.

2.2.3. Spawning frequency, season and time

Abalone in the wild spawn frequently once they have reached maturity and will also spawn in captivity provided that they are maintained in good condition. Whilst species that live in temperate waters spawn only during the warmer summer months, *H. asinina* spawns all year round although there may be seasonal peaks.

For example, *H. asinina* in southern Lombok waters displayed year-round spawning with a high proportion of spawning occurring in August-November (Setyono, 2003). Castanos (1997) reported a monthly peak in October in Thailand. In the Semporna area, mature specimens have been found at all times of year but detailed surveys have not yet been carried out to determine if there are peak seasons.

Spawning is cyclical, occurring at new moon and full moon. Males and females spawn on the same night and within 90 minutes of each other, especially in broodstock taken from the wild. The natural course of events is for males to release their sperm first. The presence of sperm in the water then stimulates the females to release their eggs.

Spawning may be spread over 2 or 3 days because not all of the animals will release gametes on the same night. The 'recovery time' needed before individuals can spawn again is unknown.

2.2.4. Spawning procedures at Boheydulang hatchery

If abalone are mature and maintained in peak condition they will spawn spontaneously, even when the males and females are in separate tanks. The advantage of this approach is that the concentration of gametes can be determined and the eggs and sperm then mixed in the correct proportion.

Spawning of males and females in separate tanks has been done at the Boheydulang hatchery but a greater spawning success rate has been achieved by placing males and females in the same fertilisation tank so that release of sperm stimulates the female to release eggs.

Figure 7. Sorting mature abalone prior to spawning.

Males and females are sorted into separate baskets in the ratio of one male to 3 or 4 females and the two baskets tied together with the males underneath (Figure 8). The baskets are placed in 400 litre spawning tanks containing irradiated water and aerated from underneath to ensure good water circulation. Transfer is done at dusk (around 6pm). The lights are then turned off and the animals left overnight.

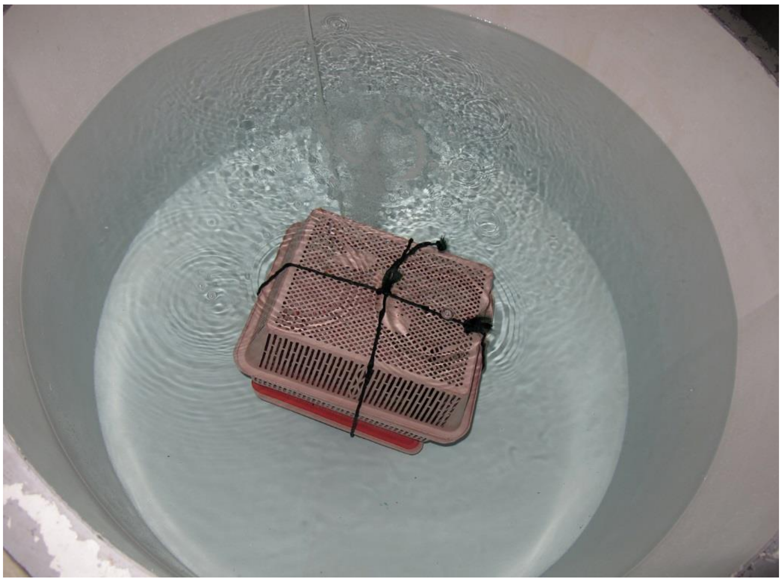

Figure 8.

Abalone baskets in the spawning tank

Varying numbers of mature individuals have been used for spawning, in the ratio of one male to either 3 or 4 females, as recommended by SEAFDEC (SEAFDEC Aquaculture Department 2000). Even if they appear to be mature, not all the animals will spawn on a given night and it is advisable to have at least 15-20 females in each fertilisation tank to allow for this eventuality. Having a larger number also helps to ensure that genetic diversity is maintained.

If abalone fail to spawn spontaneously, there are various methods that can be used to induce spawning. Both dessication and thermal shock have been used successfully at Boheydulang. With the former, mature individuals were exposed to air for about 30 – 60 minutes then placed into the spawning tanks at dusk. For the thermal shock inducement, a heater was placed in the spawning tank and the water temperature raised from 30^{o}C to 32^{o}C prior to the abalone baskets being placed in the tank.

2.3. Culture from egg to juvenile

2.3.1. Rearing eggs and planktonic larvae

Spawning takes place between 11pm and 3am and fertilisation occurs within 1-2 hours. Good quality eggs are green in colour, sink to the bottom and do not clump together (Hone *et al.*, 1997). At around 6am the upper water layer of the tank is drained off to get rid of unfertilised gametes. The eggs are then washed several times with irradiated water, ensuring that the temperature remains constant. Development is monitored by removing 5ml samples for examination under the microscope and counting the number of developing eggs.

The abalone life cycle includes two short, non-feeding larval stages (trochophore and veliger). Developing embryos of *H. asinina* are reported to hatch into a trochophore larva about 8 hours after fertilisation but faster development times have been recorded in the Boheydulang hatchery.

Development of egg

1: Polar bodies appear on fertilized egg
2: 2-cell stage
3: 4-cell stage
4: 8-cell stage approx. 2 hrs
5: 16-cell stage
6: morula stage
7: gastrula stage approx.5 - 6 hrs
8: trochophore in egg membrane

Larval stages
9: newly hatched trocophore Approx. 8 hrs
10: early veliger - 15 hrs
11: late veliger - 48 hrs

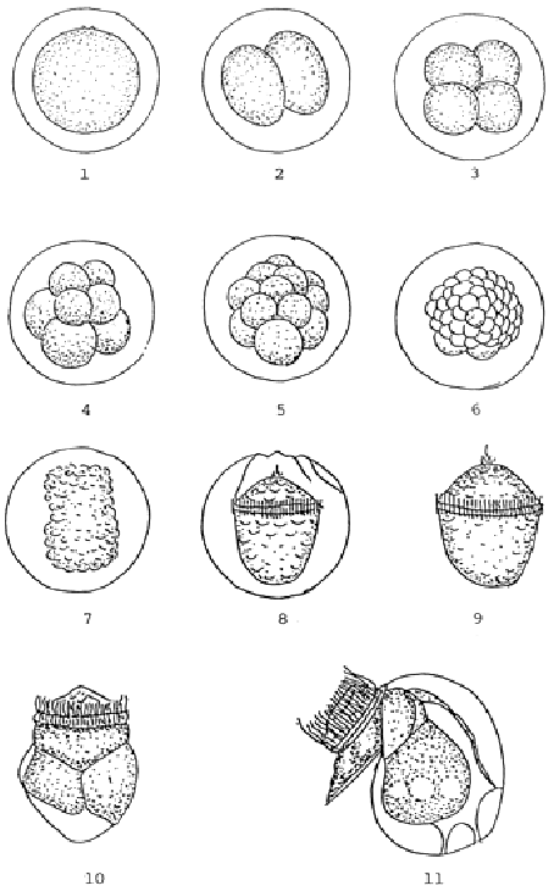

Figure 8.

Stages in development of *Haliotis asinina* using information in Williams and Degnan, 1998 and drawings from http://www.fao.org/docrep/field/003/AB731E/AB731E01.htm#chp13.1.4

Hatched trochophore larvae are approximately 200 µm in size, lecithotrophic (i.e. draw their nutrition from the yolk sac), and positively phototactic (swim towards the light). When a large number of trochophores have hatched they can be seen as a mass of pale green-white dots just under the surface of the water. The hatched larvae are siphoned off into rearing tanks containing filtered, irradiated seawater where further development takes place.

The trochophore has a ciliated band called the prototroch (see stage 9, Figure 8), which gradually transforms into a ciliated organ called the velum as it develops into the next larval stage – the veliger. The shell first starts to form at this larval stage.

Certain larval structures indicate when larval development is complete and the larva is ready to settle (Hahn, 1989). ‘Competent’ larvae are veligers which have not lost their ability to swim or crawl and have not yet changed shape. The larvae are able to return to a swimming mode after an initial settlement attempt in order to find a more suitable substrate for settlement. However, there are limits to how long the larva can go on ‘seeking’ better substrata as it will eventually exhaust the yolk supply (Joll, 1996).

Larvae cultured at the Boheydulang hatchery generally reach the late veliger stage about 12-14 hours after fertilisation, which is earlier than reported from elsewhere. At this point they are transferred to the larval rearing tanks. The transition from planktonic veliger to benthic juvenile is well known as a time of high mortality in abalone culture, with survival rates of 10% or less considered normal at this stage.

2.3.2. Post-larval culture

Settling larvae have to be provided with suitable habitat and the culture tanks set up at the Boheydulang hatchery follow procedures recommended by SEAFDEC. Settlement is on corrugated PVC plates coated with a film of diatoms which simulates natural settlement conditions and provides a suitable food for the metamorphosing larvae. Optimum diatom density on the plates for larval growth is 3000 cells/mm^2. The diatom film is established in two different ways:

a) Natural colonization
Clean corrugated plates are suspended for about 14 days in circulating seawater to allow for the settlement and growth of a

diatom film over the surface. The film does not consist solely of diatoms but also includes bacteria, yeast and protozoa. To the naked eye this layer appears as a brownish film.

The microalgal layer is examined regularly under a microscope to ensure individual microalgae do not exceed 12 – 15 microns (upper size limit of food particle that newly settled abalone can ingest) (Hone *et al.*, 1997).

b) Inoculation with cultured stock.
Pure cultures of *Navicula* and *Amphora* provided by the Department of Fisheries Sabah have been cultured further at the hatchery in order to provide a sufficient number and density of cells

for the settlement plates. The cultures were added to the cleaned plates 2 or 3 days prior to the addition of the abalone larvae.

The corrugated plates are suspended vertically and close together in fibreglass tanks in the Boheydulang hatchery. When the larvae are first added to the tank the inflow and outflow are both closed in order to prevent the larvae from being washed away before they have settled. Aeration is provided at all times and flow-through is begun after about 3 days.

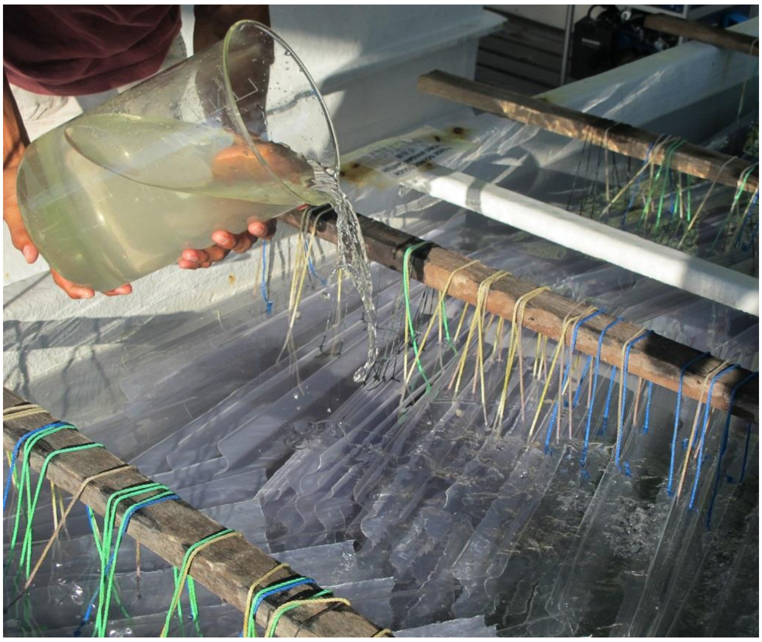

Figure 9. Abalone larvae being introduced to the diatom culture plates

The number of larvae and changes in external morphology are studied by examining a sample of plates. In the first few days the larvae can be brushed off carefully using a soft brush. However, once they are firmly attached the plates (or sections of them) are examined through a lens. Mortality rate is expected to be high during the first 60 days due to factors such as egg quality, contamination by microorganisms, water quality, and quantity and quality of feed on the settlement plates.

Figure 10. Examining the diatom culture plates (left) for 30-day old post-larva (right)

Postlarvae are reared over 60days on diatoms or until most have reached the early juvenile size ranging from 5 to 10mm at which size they are ready to feed on macro algae. At this point, fresh seaweed *Gracilaria*, cut into small pieces, is placed sparingly between the plates to initiate feeding. This allows for weaning of the larger animals while those that are below 5mm in length can continue feeding on diatoms.

2.4. Grow-out to market size

The developing juveniles are kept on the plates for 3 – 4 months by which time the shell is about 10mm in length. Research has shown that optimal survival in the grow-out phase is achieved if the late juveniles are transferred when they reach a size of 10-11mm, rather than smaller or larger (Nguyen *et al* 2010).

2.4.1. Location of grow-out facilities

Grow-out of abalone can be done in land-based facilities or in the open sea. In terms of what is feasible and suitable for local communities within the Tun Sakaran Marine Park, the best option is open sea grow-out. There are several reasons why this is the case:

a) The hatchery (Marine Invertebrate Conservation Centre) on Boheydulang is small and was designed for spawning and production of 'seed' animals (e.g. abalone, giant clams, sea cucumbers) rather than to hold large numbers of growing abalone.

b) Local communities need to be able to easily access the grow-out site(s). They would not be able to do this if the animals were on Boheydulang because all the settlements are some distance away, outside the lagoon.

c) Sea-based culture has lower capital and maintenance costs than land-based culture.

d) Sea cages are likely to have better water exchange and fewer temperature fluctuations than land-based facilities.

e) It is possible to set up polyculture systems at sea by using the same raft system to grow other species alongside the abalone and thus maximizing profits. For example, seaweed can be cultured on lines above the abalone cages or pearl oysters below (Setyono, 2005).

During the abalone fishing survey in TSMP there was strong support for the idea of farming abalone with 84% of the 26 respondents saying that they were interested in participating in the initiative. All of the respondents live close to sea areas where they have fished for abalone and therefore which could be expected to be environmentally suitable for farming these animals.

For the research and development phase, juveniles produced at the Boheydulang hatchery have been grown-out on site in order to monitor survival and growth. After 3 months and at a size of about 10mm they were transferred to sections of PVC pipe which were kept either in the raceways at the hatchery or in the adjacent sea cages. Fine mesh netting covered each end and could be easily removed when seaweed needed to be introduced.

Figure 11. Grow-out of juveniles at the Boheydulang hatchery. Top: PVC pipe providing shelter and security for growing juveniles. Bottom left: mesh removed to show approximately 1cm juveniles and 4cm sub-adults. Bottom right: 3-4 month-old abalone.

2.4.2. Grow-out systems

Generally either plastic barrels and/or mesh cages are used for ocean rearing of abalone. The plastic barrels are rigid and have cut-out windows in order to ensure good water flow. They are more expensive than cages and are not available locally. In addition, water circulation in barrels is less good. Cages are therefore the preferred method for the TSMP community programme.

Floating net cages are currently being constructed, following the design shown in Figure 12. The frame is being made from PVC piping about 3cm diameter and then covered by mosquito netting which is readily-available and has a mesh size of about 500 microns. A mesh window is incorporated in order to provide access to the cage.

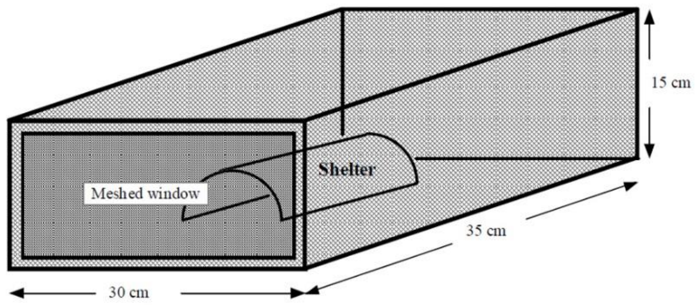

Figure 12. Floating net cage design for abalone grow-out