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Review Article

Prevailing Knowledge on Aquaculture of Abalone in Southeast Asia: A Review

Nur-Syahirah Mamat[1], Yuzine Esa[1,2,3]*, Hidayah Manan[4], Nur Leena W. S. Wong[1,2], Julia D. Sigwart[5,6], Siti-Azizah Mohd Nor[7], Nazia Abdul Kadar[8], Hon Jung Liew[4], Jalilah Mohamad[4], Suhairi Mazelan[4], Khor Waiho[4] and Aziz Arshad[2]

[1]*International Institute of Aquaculture and Aquatic Sciences, Universiti Putra Malaysia, 71050 Port Dickson, Negeri Sembilan, Malaysia*
[2]*Department of Aquaculture, Faculty of Agriculture, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia*
[3]*Department of Aquaculture, Faculty of Fisheries and Marine, Universitas Airlangga, Campus C Jalan Mulyorejo, Surabaya, 60115 East Java, Indonesia*
[4]*Higher Institution Centre of Excellence, Institute of Tropical Aquaculture and Fisheries, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia*
[5]*Department of Marine Zoology, Senckenberg Research Institute and Museum, Frankfurt, Germany*
[6]*Queen's University Belfast, Marine Laboratory, Portaferry, Northern Ireland*
[7]*Institute of Marine Biotechnology, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia*
[8]*Borneo Marine Research Institute, Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia*

ABSTRACT

Abalone is a marine gastropod mollusc with significant economic importance in global fisheries and aquaculture. Currently, the abalone culture is actively engaged in Southeast Asia and has gained significant popularity among aquaculturists and aquafarmers in Indonesia, the Philippines, Thailand, Vietnam, and Malaysia. Abalone also has emerged as a highly profitable source of income for fish farmers in Asian countries. The exquisite taste of abalone has made it a sought-after delicacy, particularly in Chinese cuisine. However, scanty documentation of this marine gastropod has been reported on the development of aquaculture production in Southeast Asia. Therefore, to help bridge the gap, this review emphasised the information and collated ideas on the industrial culture of abalone in Southeast Asia. In this review paper, all issues on abalone culture will be summarised and highlighted,

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E-mail addresses:
nsyahirahmamat@gmail.com (Nur-Syahirah Mamat)
yuzine@upm.edu.my (Yuzine Esa)
hidayahmanan@umt.edu.my (Hidayah Manan)
nurleena@upm.edu.my (Nur Leena W. S. Wong)
julia.sigwart@senckenberg.de (Julia D. Sigwart)
s.azizah@umt.edu.my (Siti-Azizah Mohd Nor)
nazia@ums.edu.my (Nazia Abdul Kadar)
honjung@umt.edu.my (Hon Jung Liew)
jalilah@umt.edu.my (Jalilah Mohamad)
suhairi@umt.edu.my (Suhairi Mazelan)
waiho@umt.edu.my (Khor Waiho)
azizarshad@upm.edu.my (Aziz Arshad)
*Corresponding author

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especially on the aquaculture industries of abalone, challenges and constraints in developing the aquaculture of *Haliotis* spp., and biological features of the abalone. This review paper could be a valuable reference for abalone aquaculture practices in Southeast Asia, with the aim of boosting production and conservation efforts of these marine gastropod molluscs, thereby benefiting abalone aqua farmers in Southeast Asian countries.

Keywords: Abalone, aquaculture, *Haliotis* spp., marine gastropod, Southeast Asia

AN OVERVIEW OF AQUACULTURE ABALONE

Since the late 1990s, there has been a significant global demand for abalone products, mostly from Asian countries, relative to market supply (Cook & Gordon, 2010). In Southeast Asia, the Philippines was identified as the major producer of abalone from commercial capture fisheries, where in 1996, the Philippines recorded as much as 448 metric tons per year of harvested abalone. Commercial abalone aquaculture and fisheries in the Philippines have been developed rapidly with the well-established seed production, hatchery and grow-out culture of *Haliotis asinina* (Fermin, 2001). Abalone production in the Philippines showed increasing trends as demand in seafood markets increased in Asian countries (Salayo et al., 2020). Since 1991, the Philippines has also successfully exported abalone to several countries, such as Hong Kong, Japan, the United States, Singapore, and Australia. The success in the hatchery and nursery of abalone aquaculture has produced seed stocks for growing abalone in the Philippines (Lebata-Ramos et al., 2021; Mabuhay-Omar et al., 2021).

Haliotis asinina, a donkey's ear abalone, is a native species in Thailand, Indonesia, Malaysia, Vietnam, and the Philippines. It is a species with significant aquaculture potential in Southeast Asia due to its fast growth rate, high percentage of edible parts, and high survival rate when cultured either on land or in a sea-based culture system compared to other abalone species (Fermin, 2001; Kua et al., 2011). This species has the ability to spawn and mature within one year (Wood et al., 2015). This species is also commercially high-value seafood harvested by fishers (Salayo et al., 2020). Previous research papers published show that this species was successfully cultured in Thailand (Nuurai et al., 2010), Vietnam (Minh et al., 2010), Indonesia (Maulidya et al., 2021), the Philippines (Lebata-Ramos et al., 2021) also in Malaysia (Kua et al., 2011) through the hatchery and farming culture operation.

In Malaysia, Sabah was identified as an area with a high abundance of *H. asinina*, where this species is collected for domestic uses and exported (Kua et al., 2011; Wood et al., 2015). As far as literature is concerned, studies on aquaculture abalone in Malaysia used only samples from the coastal water of Sabah with only from *H. asinina* species (Nhan et al., 2010; Kua et al., 2011; Wood et al., 2015). Harvesting was unregulated; therefore, no data on the population status was available. The distributions of abalone species in Peninsular Malaysia are still in question, and no documented reports exist. Sabah Parks initiated abalone breeding in the mid-1990s at Boheydulang island, Semporna (Sabah waters), to support local livelihood solely depending on fishing abalone (Wood et al., 2015). Then, in the 2000s, abalone breeding was conducted by the Fisheries Research Institute (FRI) due to high demand among Malaysia's Chinese populations. Species of *H. asinina* identified appear in the shallow reefs around the Sabah waters, including Mantanani Island and islands surrounding the Semporna waters (Kua et al., 2011). Omadal and Kulapuan islands located at Semporna have an active abalone fishery and supplied broodstock where the abalone price can reach up to RM 25 per kg (~USD5) (Wood et al., 2015).

Meanwhile, in 1991, the Coastal Development Centre in Rayong Province of Thailand successfully increased the fecundity of *H. asinina* (Apisawetakan et al., 1997), and in 1996, the first commercial abalone plantation was established on Phuket Island in southern Thailand (Wetchateng et al., 2010). Due to high meat yield, most abalone farms in Thailand culture the native species, *H. asinina*, as the selective type of abalone species to be cultured (Wetchateng et al., 2010). In the past decade, Thailand also have conducted research on the culturing of *H. asinina* (Jarayabhand & Paphavasit, 1996; Thongrod et al., 2003) with more updated studies on *H. asinina* on aspects of culture, including energy gained from feeding (Ganmanee et al., 2010), effects of stocking density on growth performance (Jarayabhand et al., 2010) and effects of hormone on reproduction (Nuurai et al., 2010).

Since 1997, Vietnam has also conducted a series of research on the aquaculture of abalone in a few species, including *H. asinina* (Minh et al., 2010; Minh & Hong, 2000), *Haliotis ovina* (Thao et al., 2020) and *Haliotis diversicolor* (Chieu et al., 2016). Among the studies are on reproductive biology (Minh & Hong, 2000), growth performance (Minh et al., 2010) and seed production (Chieu et al., 2016). In Indonesia, live abalone is much more expensive and can be sold at Rp. 150,000 (~ USD10) per kg; meanwhile, for dry abalone, the price is from Rp. 350,000 (~ USD23) and can reach up to Rp. 500,000 (~ USD32) per kg (Grandiosa, 2020). In the Philippines, live abalones command a high price of P300 (~USD5) per kg (15–20 pieces), and the blanched meat is sold at P550 (~USD10) per kg (Gallardo & Salayo, 2003). In addition to legal (overfishing) and illegal (poaching) harvesting as well as habitat disturbance, this situation has led to the depletion of abalone stock in nature of Southeast Asia, particularly Indonesia, Philippines, Thailand, and Malaysia (Sososutiksno & Gasperz, 2017). The deterioration of abalone stock is also identified as being affected by the disease, increased predation, and habitat degradation. The abalone aquaculture industry and its development through research in various parts of the world is increasing rapidly. It focuses on developing broodstock management, larval rearing, nursery and growth techniques (Grandiosa, 2020).

BIOLOGY AND IMPORTANCE OF ABALONE IN AQUACULTURE

Abalone is a herbivorous marine gastropod from the only genus in the Haliotidae family, *Haliotis*, with a univalve (single spiral shell) and a row of holes along the left margin of the shell (Geiger & Poppe, 2000) (Figure 1). The shell is on the top and covers most of the abalone's body (Figure 2). Abalone is a nocturnal mollusc, and its feeding habits mainly occur at nighttime by consuming benthic diatoms during the larvae stage and actively grazing on micro and macro algae at the adult stage (Grandiosa, 2020). Abalone is considered one of the most vital marine molluscs in fisheries and aquaculture worldwide. The global production of abalone has increased significantly in recent years, and its production now relies mostly on aquaculture, although previously, the production depended primarily on fisheries (Hernández-Casas et al., 2023).

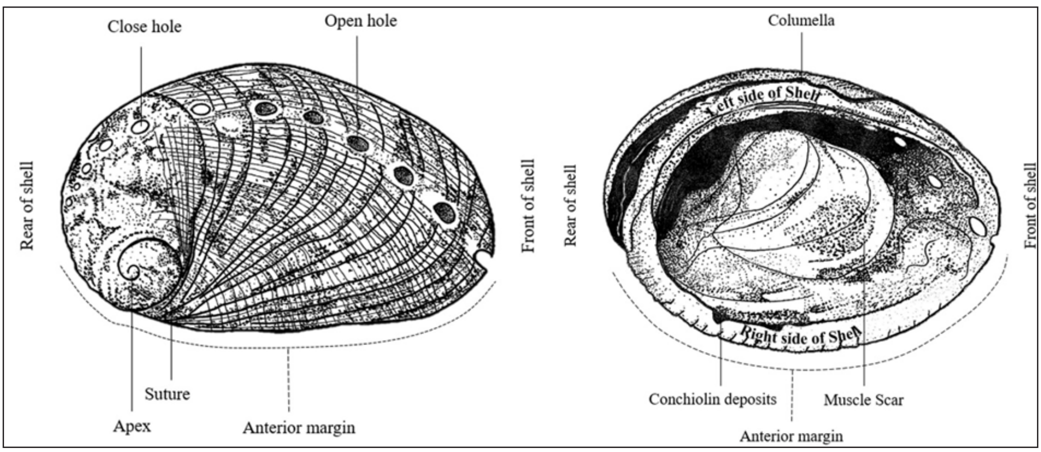

Figure 1. Diagram of external anatomy of abalone modified from Geiger and Poppe (2000)

Due to high demand and high price, abalone has become a profitable income source for fish farmers in Asian countries, especially in Indonesia (Sososutiksno & Gasperz, 2017), the Philippines (Capinpin et al., 2015), Vietnam (Chieu et al., 2016) and Malaysia (Wood et al., 2015). In Asian traditions, abalone is consumed as a premium and luxury seafood product that symbolises "wealth and power" and is referred to as "table gold" (Li et al., 2022). The significantly high market value of abalone aquaculture renders it commercially appealing due to the delicacy of its unique texture and flavour, which has an exquisite taste. Abalone also perceived the benefits of increasing vitality and nutrition (Grandiosa, 2020).

Concordant with the development of the economy, consumers have paid attention to the nutritional quality of abalone, which enhances health, decreases the occurrence of diseases, and extends lifespan by consuming essential nutrients (Li et al., 2022). The composition of abalone muscle contains protein, carbohydrate, fat, and ash (Shi et al., 2020). Proteins play a crucial role in determining the nutritional content of food, and abalone muscle is rich in high-quality protein. The rich source of protein in abalone assists in preserving a wide range of health aspects. In addition, abalone can assist in the absorption of polyunsaturated fatty acids and essential amino acids, which contribute to developing cardioprotective dietary patterns (Tsai et al., 2018). Abalone also has a reduced caloric content compared to other types of shellfish (De Zoysa, 2013).

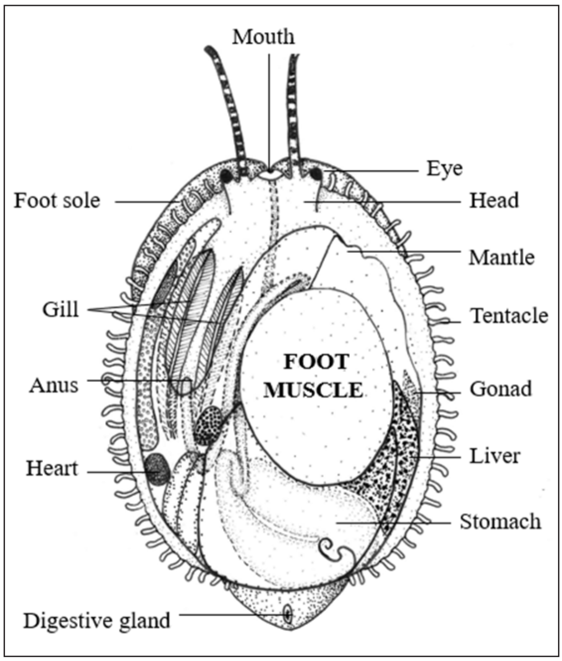

Figure 2. Diagram of the internal anatomy of abalone modified from Geiger and Poppe (2000)

Abalone is recognised to have bioactive components that can benefit health in addition to being consumed, including anticancer, antioxidant, anti-microbial, anti-coagulant, and benefits for cosmetics (Nguyen et al., 2013). Due to various benefits exhibited to human health, abalone is known as "the emperor of the seashells," "ginseng in the ocean," or "mother of shellfish" (De Zoysa, 2013). Abalone shells are renowned for their magnificent iridescent features. They have been used for numerous purposes in many cultures and industries, as shells are used for decoration, art crafts and souvenirs. Shells are also used to make jewellery such as buttons, necklaces, rings, bracelets and beads (Grandiosa, 2020; Maulidya et al., 2021). Meanwhile, in indigenous cultures, abalone shells have been used in traditional ceremonies and rituals (Gamble, 2017). Therefore, it is economically viable for aquaculture as there is a significant market demand for abalone in various markets around the world, contributing to the sustainability and profitability of seafood production.

CULTURE TECHNIQUE AND RESEARCH FOR ABALONE AQUACULTURE

There are three main parts of abalone culture: (1) the larvae-rearing phase, (2) seed production, and (3) the grow-out phase of juveniles to marketable size. Wood et al. (2015) stated that the dividing phase is based on the abalone life cycle, which can comprise two different ways of living: a) free-swimming and non-feeding larval stages (trochophore and veliger) and b) settling down on substrate and eating microalgae plus algae (juvenile and adult stage). Larvae production in the hatchery is usually done inland, while grow-out production can be land- or sea-based. A full understanding of the abalone pelago-benthic life cycle is needed to properly plan and manage their culture, as it is highly susceptible to environmental changes. Hatchery production focused on rearing trochophore and veliger phase larvae until they successfully formed into the juvenile stage. The schematic diagram of the abalone life stage is shown in Figure 3.

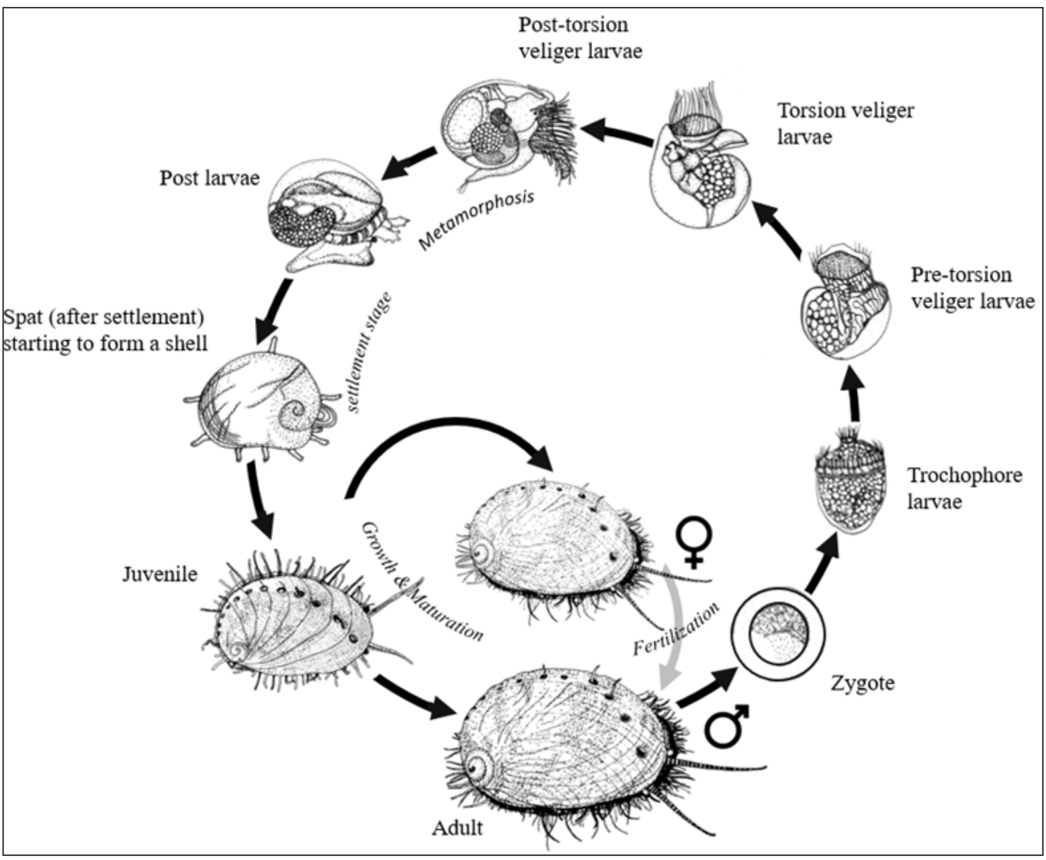

Figure 3. The pelago-benthic life cycle of abalone started from zygote to trochophore, changed to veliger larvae, then changed to post larvae, then changed to spat, then changed to juvenile and lastly, adult stages modified from Jardillier et al. (2008)

Larvae Rearing Phase

The newly hatched trochophore larvae are free-swimming towards the light (positively phototactic), 200 µm in size per each, surrounded by ciliated named prototroch, only depends on nutrition from yolk sack or and in groups, they can be seen as the light green-white dots under the surface of the water (Wood et al., 2015). After 22 h, the prototroch of trochophore larvae progressively transformed into an organ called velum, and at this time, the larvae enter into the veliger phase larvae. At the veliger phase, the larvae are still in free-swimming form and start absorbing the soluble nutrients from their surroundings through the skin, but they still depend on the remaining egg yolk. The veliger phase larvae are actively searching for suitable settlement spots of the substrate and gradually attempt to settle until contentment. However, the distance and a total attempt to settle are limited and depend on the remaining energy of the yolk supply.

At most, the free-swimming larvae take seven days or less (depending on temperature) to settle to subtracts in the rearing tank and become postlarvae (Najmudeen & Victor, 2004; Wu & Zhang, 2016). Post larvae fully shed their cilia, settle on the substrate, establish the shell, and develop into adult form. However, transitioning from the veliger stage to becoming benthic post larvae is extremely challenging. At this time, a high mortality rate is identified, around 10% or less of survival rates (Wood et al., 2015). Furthermore, the low quality of eggs, low water quality and microorganism contamination can contribute to mortality. Post-larval cultures are still in the hatchery phase and reared over 60 days or until they become juvenile size at 5-10 mm at the size that is able to eat macroalgae. The post larvae are tempted to settle on the substrate coated with layers of diatom (microalgae) with an optimum density of 3000 cells/mm^2 as food for the larvae (Wood et al., 2015).

The quality and quantity provided as feed on settlement plates determine the survival rates of the larvae. The common diatom selected as a starter food for abalone post-larval is *Navicula* sp*., Amphora* sp. and *Nitszchia* sp. (Avendaño-Herrera et al., 2007). A study by Gallardo and Buen (2003) also found that larval attachment was higher on mucus and *Navicula* than on other diatoms. The diatom film can be established in the culture tank by natural colonisation or seeding with cultivated stock. In the larval settlement process, substrate difference and feed type affect abalone growth's success rate (Williams et al., 2008). After 60 days of feeding with diatoms, the post larvae entered the juvenile stages. They were introduced to macroalgae, seaweed such as *Ulva lactuca*, green filamentous algae, and coralline red algae as food. According to Najmudeen and Victor (2004), the different types of seaweed can affect the colourizations of the juvenile shell, and the tropical abalone, *Haliotis varia*, which feeds with coralline red algae, displayed the best growth rate performance. The developing juvenile is left to grow in the hatchery at the rearing phase for three to four months until the size becomes 10mm long.

Conventionally, abalone spawning and nursery processes are done under controlled conditions in a hatchery before they reach juvenile size for the grow-out process in the open ocean until market size (Wood et al., 2015). With the advancement in abalone farming technology, farming abalone is now cultured fully indoors from larvae to adult market size by using a raceway system where super filtered and sterilized sea water continuously flows over the rearing tanks, delivering oxygen and carrying away waste (Heasman & Savva, 2007). Table 1 lists water quality for breeding abalone in Southeast Asia countries, including Malaysia, Indonesia, the Philippines, Thailand and Vietnam. Most studies were conducted on *H. asinina*, the most widespread species in Indo-Pacific oceans.

Table 1
List of water quality for breeding of abalone in Southeast Asia

Country	Species	Temperature (°C)	pH	DO (mg/L)	Salinity (ppt)	Reference
Malaysia	*Haliotis asinina*	25–31	6.5–8.5	6.0–7.5	29–33	Nhan et al. (2010)
Indonesia	*Haliotis asinina*	26–28.5	7.5–7.8	5.7–7.6	32–34.5	Hamzah (2012)
	Haliotis squamata	28.1–29.9	7–8.5	8.2–10.1	29.6–34	Sahetapy and Latuihamallo (2014)
	Haliotis squamata	27–28	7–8	> 4	30–35	Ardi et al. (2020)
	Haliotis squamata	27–28	-	-	32–33	Hadijah et al. (2021)
	Haliotis asinina	27–31	8.3–8.4	5–5.6	28–35	Amin et al. (2020)
Philippines	*Haliotis asinina*	26–30	7.9–8.8	4.1–6.4	30–35	Fermin and Buen (2001)
	Haliotis asinina	28–31	8.3–8.4	5–5.6	28–32	Bautista-Teruel et al. (2003)
	Haliotis asinina	27–29	-	-	32–35	Gallardo and Salayo (2003)
	Haliotis asinina	26–27	7–8.2	-	35–38	Jumah et al. (2016)
Thailand	*Haliotis asinina*	27–30	8.3–8.4	6	29–32	Thongrod et al. (2003)
	Haliotis asinina	25–26	-	-	25–32	Stewart et al. (2008)
	Haliotis asinina	28	-	-	31	Ganmanee et al. (2010)
Vietnam	*Haliotis asinina*	27–28	-	-	30–34	Minh and Hong (2000)
	Haliotis asinina	23–31	7.8–8.4	4.5–6	30–32	Minh et al. (2010)

Seed Production

The availability of a reliable seed supply is crucial for commercial production (Hamka & Shearer, 2009). Other countries have developed many abalone hatcheries to produce abalone seed for commercial farming and to improve natural stocks (Setyono, 2005). The seed of production of *H. asinina* in Indonesia started in 1997 but only succeeded in 2003 after five years of research (Hamka & Shearer, 2009). Hamzah et al. (2012) compared the effect of different densities of abalone seeds (75, 50 and 25 individuals per tank) on survival and growth. General findings indicated that the highest survival rate was observed in the tank with 75 individuals, while the highest growth rate was recorded in the tank with 50 individuals. However, research showed that the abalone seed density does not influence the growth and survival of abalone seeds. This is due to the characteristics of abalone, which stick together in groups and only spread during feeding time (Hamzah et al., 2012).

The abalone seedlings are assumed to continue to be produced in aquaculture centres owned by the government in Indonesia due to the availability of established protocols (Grandiosa, 2020). In addition, feeding with immunostimulants, such as probiotics, may significantly boost the immunity and the survival of abalone seeds towards the disease, leading to fast abalone growth. The Aquaculture Department of the Southeast Asian Fisheries Development Centre (SEAFDEC/AQD) in the Philippines has classified abalone as a species for enhancement programs aiming to boost production. It has successfully produced *H. asinina* seeds in the hatchery (Lebata-Ramos et al., 2013). It is suggested that the minimum size of seeds of *H. asinina* for release is 3 cm shell length (SL) (Lebata-Ramos et al., 2013), which is supported by a study from Masuda and Tsukamoto (1998) that indicated that after one year of release (SL of 2, 3, and 4 cm), the survival rates were 10%, 30-60%, and 70-80%, respectively.

The larger size showed a higher survival rate compared to the smaller size, indicating that a release of larger abalone is ecologically more productive for survival in the wild. In Vietnam, a massive quantity of abalone seeds of *Haliotis diversicolor* has been produced from artificial reproduction conducted by the Research Institute for Marine Fisheries, aiming to restock and increase the income of local communities (Chieu et al., 2016). Abalone seeds can be managed based on a few techniques: (1) the seeds are stocked in protected areas, and (2) the seeds are commercially maintained using containers until certain periods (size suitable for sale) before being harvested and sold to consumers (Eny & Setyono, 2007). A study by Supriyono et al. (2020) suggests that a flow-through system can produce abalone seed production as this system can improve abalone's growth and survival rate. The authors also suggest that an additional 15 mg/L of calcium oxide (CaO) will increase the survival rate of abalone seed production.

Abalone with shell lengths between 2-3cm are selected for enlargement of abalone seeds. Poly Vinyl Chloride (PVC) pipe was commonly used for commercial abalone seed techniques in which the seeds will attach to that PVC pipe (Figure 4). This cut PVC pipe is beneficial as a substrate and a shelter and allows abalone seeds to adjust to the environment (Maulidya et al., 2021). It is also reported that the survival rate of abalone seeds was high using this technique (Lebata-Ramos et al., 2013). With the advance in technology upgrades, it is expected that the seed production of *H. asinina* and *Haliotis squamata* in Indonesia will be capable of pursuing the production target of at least 1 billion seeds by 2023 to support the target of increasing exports in 2024 (Grandiosa, 2020).

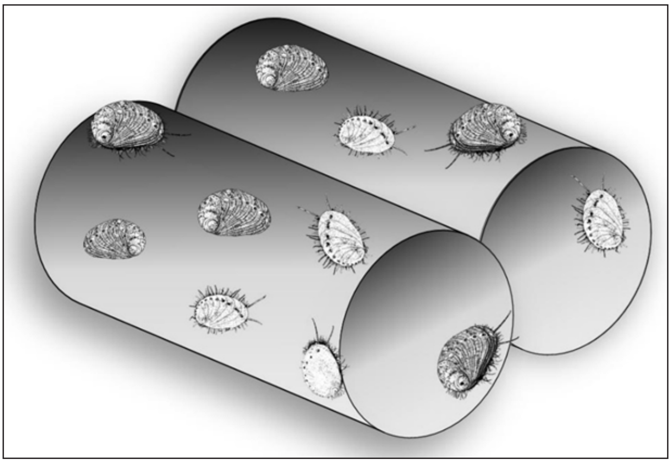

Figure 4. Abalone seeds were attached to the cut of PVC pipes that act as a substrate and shelters modified from Maulidya et al. (2021)

Grow Out Culture

The juvenile that enters the grow-out phase will transfer to grow-out facilities if the culture is land-based or to the selected area in the open sea if the culture is sea-based. Land-based cultures can be found in onshore ponds, raceways, or tanks. Sea-based cultures are kept in intertidal ponds, cages, barrels, enclosed piles of rocks, or through sea ranching (Gallardo & Salayo, 2003). Minh and Hong (2010) emphasised that the most suitable size for transferring juveniles from hatchery to grow-out site sites cannot be more than 10 to 11 mm to ensure the optimal survival rate. The open sea-based is the best option over land-based for the grow-out phase of abalone due to several reasons: (1) can accommodate a large amount of growing abalone at one time without limit as long as the selected area is broad and suitable, (2) lower fund and management costs, (3) having natural water exchange that can control water quality and water temperature instabilities minimally occur, (4) easy access for the local community to enter the site, and (5) can possibly accommodate the polyculture system set up for culturing other species together with abalone and thus save cost plus making largest profits, for an example culturing seaweed above the abalone cages (Wood et al., 2015; Wu & Zhang, 2016).

Even though farmers rarely choose land-based grow-out facilities due to high operational costs and limited culture space for growing abalone, which depends on the size of built facilities, the management and maintenance of culture stock and disease control can be monitored easily compared to open sea-based grow-out. Sufficient food and moderate temperature alongside suitable stocking densities in land-based grow-out facilities can ensure a higher survival rate and optimum growth rate of abalone (Huang & Hseu, 2010). In addition, cultured tropical abalone species normally achieve marketable size in only one year compared to temperate species, which take two to three years (Gallardo & Salayo, 2003; Gao et al., 2023). However, if high-tech systems were used in the cultured environment such as systems that allow easy control of temperature and water quality, the opportunity to speed up the harvestable period is possible, and farm profits may also be increased.

The most grow-out systems selected by farmers for open sea-bases are (1) mesh cages and/or (2) plastic containers with cut-out windows (or perforated baskets) for water flow movement (Wood et al., 2015). The facilities required for the hatching process, such as a net floating cage as the main rearing media, an aquarium as media to prepare gonad ripened broodstock, fibre tanks used for egg hatching and larva rearing media, and concrete tanks also used for larva rearing. A net floating cage is practical economically and financially for abalone culture with an Rp. income of 45000 (~USD 3) and a profit of Rp. 22800 (~USD1.5) (Sososutiksno & Gasperz, 2017). The structure of net cages can be rectangular or circular, and they also use unused tyres covered by a net (Setyono, 2005). Previous studies have proved the high successful survival rates of juveniles cultured of *H. asinina* in net cages offshore of Pemenang, West Lombok of Indonesia was around 93% to 95%. In a commercial application, net cages can be changed to cages made from rattan, wood, or bamboo, which provide more proper shelter for the juveniles while allowing adequate water to flow through the cages (Setyono, 2005).

Previous research by Setyono and Aswandy (2010) investigated the most suitable technique for culturing abalones using two structure types (TNC = tyre net cage and CNC = circular net cage). Results identified showed that the juveniles of *H. asinina* have better growth when cultured offshore using TNC compared to CNC. Another study by Capinpin et al. (2015) uses PVC pipes as shelter to compare the difference in the behaviour, rate of growth and recovery rates of hatchery-reared abalone juveniles with wild abalone. After one day of deployment, the wild abalone is able to immediately disperse into the surrounding environment. Meanwhile, wild seed abalone growth rates were similar to those of abalone culture in tanks. In terms of recovery rates, both hatchery-reared and wild abalone showed recovery rates of 3% - 4% after 105 days, which indicated that although the implementation of stock enhancement was very costly, it was able to help restore the depleted populations of marine animals (Capinpin et al., 2015).

A study by Ardi et al. (2020) uses different shelter shapes: (1) Round, (2) Square, and (3) Without shelter to examine the growth and survival of abalone (*H. squamata*). The shelter is made from PVC piping. Findings from this study showed that the use of shelter has a significant and better effect on the growth of abalone culture, which is also supported by previous studies that the growth of patterns of both shell length and wet weight abalone were higher than abalone without shelter (Lloyd & Bates, 2008). The finding also discovered that abalone preferred to grow on and be sheltered in the culture rather than without sheltered and increased surface area (Ardi et al., 2020). Among the shelter shapes, a round shape showed the best result for growing abalone in the tidal area. The other study was conducted on the nursery and grow-out culture of *H. asinina* on a reef flat using four different culture containers: cage, recycled oil container, tray (control) and tube with the main purpose of comparing the growth and survival rates (Lebata-Ramos et al., 2021).

According to Lebata-Ramos (2018), the culture container is one of the most crucial inputs for large-scale grow-out culture. These containers ought to be affordable to both local low-wage earners and capitalists, reusable for several culture runs, and able to endure strong wind conditions. Findings showed that growth rates of *H. asinina* vary greatly depending on the culture conditions. However, with proper culture containers, optimum culture environment and sufficient food, non-significant differences in SL of abalone in the three culture containers in both nursery and grow-out cultures were found. Among the containers, tubes are most recommended for use when doing culture, particularly on reef flats, as these tubes are the most stable and durable enough to withstand harsh environmental conditions (Lebata-Ramos et al., 2021). All these examples indicate that the optimisation of production systems is critical as these systems directly affect the growth and survival of the species in culture.

CONSTRAINTS AND CHALLENGE IN ABALONE CULTURE

As the demand for abalone keeps increasing, there is a need to make the production of abalone robust. One of the initiatives that can be applied is the systematic breeding programme for both wild population enhancement and aquaculture purposes. However, various challenges emerged that have limited abalone aquaculture production, such as disease infections, environmental changes, slow growth rate, and lack of quality seed and feeding behaviour (Wiradana et al., 2018; Wu & Zhang, 2016). Therefore, prior to future studies, it is crucial to know the factors that can affect the abalone culture as knowledge is needed to develop and expand abalone aquaculture in Asia (Wetchateng et al., 2010).

Disease Infections

The development of aquaculture based on the intensification and commercialisation of marine products, including abalone, will raise the prevalence towards significant diseases as the movement of animals can lead to the spread of pathogens to the susceptible host during the harvesting and handling process (Mabuhay-Omar et al., 2021; Wiradana et al., 2018). Past research has shown numerous pathogens that cause serious abalone diseases have been reported from different abalone species around the world, such as *Haliotis tuberculata* (Nicolas et al., 2002), *Haliotis diversicolor* (Wang et al., 2004) and *Haliotis* *gigantea* (Kamaishi et al., 2010). *Vibrio* species are the most commonly encountered bacterial agents associated with diseases in marine and brackishwater systems in tropical environments (Handlinger et al., 2005).

Vibrio is a ubiquitous opportunistic pathogen that is constantly present in water. *Vibrio* species are problems in molluscan shellfish hatcheries, including abalone (Handlinger et al., 2005; Kua et al., 2011). The disease outbreak only occurred in disease-supporting environments, indicating that environmental factors have a significant impact on vibriosis epidemics (Istiqomah & Isnansetyo, 2020). Among the major *Vibrio* species that infect abalone species are *Vibrio parahaemolyticus*, *Vibrio harveyi*, *Vibrio splendidus*, *Vibrio aglinolyticus*, *Vibrio anguillarum*, and *Vibrio vulnificus* (Cai et al., 2006; Handlinger et al., 2005; Pitchon et al., 2013). Outbreaks of vibriosis also have been reported in the population of abalone in Southeast Asia, such as in Indonesia (Giri et al., 2014), Thailand (Tangtrongpiros & Chansue, 1999; Wetchateng et al., 2010), the Philippines (Mabuhay et al., 2021; Santiago & Mabuhay-Omar, 2019) including Malaysia (Kua et al., 2011).

The outbreak can be detected in different parts of the abalone, such as the mantle, gill, gut, digestive tract, and foot (Giri et al., 2014; Kua et al., 2011; Mabuhay et al., 2021). A study by Giri et al. (2014) showed that an infection caused by *Vibrio* species bacteria is indicated by the presence of mantel epithelium and digestive tract epithelium erosion with abundant secretion and degradation, as well as the presence of mantel muscular abscess. A study by Yasa et al. (2020) reported that *H. squamata* will respond to the infection *of V. alginolyticus* with a rapidly increasing level of heat shock protein (HSP70 and HSP90) expression. Meanwhile, in Thailand, the first observation of the Withering syndrome (WS) in abalone that was recorded in the small abalone, *Haliotis diversicolor supertexta*, was caused by an infection with the Rickettsia-like organism (RLO) 'Candidatus Xenohaliotis californiensis' (WS-RLO) agent (Wetchateng et al., 2010).

Other previous research conducted in Thailand reported that the occurrence of abdominal swelling disease in *H. asinina* was caused by *Vibrio cholerae, Escherichia coli* and *Pseudomonas fluorescens* detected in the blood and gastrointestinal tract (Tangtrongpiros & Chansue, 1999). In Malaysia, the high mortality rate of *H. asinina* was recorded with white lesions and necrosis on foot caused by *Pasteurella* sp. and *Vibrio* spp. (Kua et al., 2011). To date, a study in the Philippines reported that most of the pathogenic bacteria can be found in the gut of abalone (Mabuhay-Omar et al., 2021). The finding supported the previous finding, indicating that more microorganisms can be found in the abalone gut than in the gills and mantle (Santiago & Mabuhay-Omar, 2019).

Survival Rate

Among the major problems in abalone farming is the extremely low survival rate during early juveniles (Hamka & Shearer, 2009; Minh et al., 2010). It occurs due to the small size of the abalone, which becomes a potential prey to other marine animals. Growth and survival rates of abalone at low densities (40–60 pcs/cage) were higher than the abalone at higher densities (80–100 pcs/cage) (Minh et al., 2010). The movement of abalone was limited in high stock density to reach out for food as they had to compete with other individuals. Indirectly, this will impact their feeding and living conditions, including growth and survival rate (Huchette et al., 2003). The techniques applied to release the abalones significantly influence the survival rate. The survival rate can be boosted with better maintenance practices.

In this case, the government has to play a significant role in helping local fishermen boost abalone harvest in either sea ranching or stock enhancement programmes. In addition, to properly govern the harvesting of marine resources, the implementation of legislation for the management of marine protected areas (MPAs) or fish sanctuaries must be strengthened. For example, in Indonesia, there were three main centres operating abalone hatcheries that produce seeds and culture of local abalone species under the Directorate General of Aquaculture, Ministry of Marine Affairs and Fisheries namely Tigaron Abalone Hatchery (Bali), Marine Aquaculture Development Centre (MADC) (Lombok) and the Centre for Brackishwater Aquaculture Development (Makassar) (Hamka & Shearer, 2009).

Feeding Behaviour

Food is one of the main criteria that determines the success of abalone aquaculture (Prihadi et al., 2018). Abalone needs macroalgae, such as seaweed, as a source of energy for growth and survival (Octaviany, 2007). It is suggested that three main factors affect the abalone preference for algae: morphology and texture, metabolite compounds, and the essential nutrients for the growth of abalone (Paul et al., 2006). However, the lack of information on good feed quality for abalone development and survival is another difficulty in abalone aquaculture (Hadijah et al., 2021). For example, insufficient amounts of *Gracilaria* sp. in some areas have affected abalone growth (Hamka & Shearer, 2009).

Commonly, the use of macroalgae as a natural abalone diet would result in malnutrition (Hwang et al., 2014), and due to its high moisture content, it probably can cause diseases and infection (Bautista-Teruel & Fermin, 2003). However, studies indicated that abalone fed with macroalgae significantly improves their health, product quality, and feeding behaviour compared to a formulated diet (Bansemer et al., 2016). It was in concordance with a study by Hadijah (2017), which recommended that *Gracilaria* sp. of marine algae contributed to the most optimal growth and survivability of abalone compared to other varieties of feed. Larger juvenile abalones eat macroalgae, while benthic diatoms are important food for newly settled abalones (Daume, 2006).

A balanced abalone diet must include carbohydrates, protein, lipids, vitamins, and minerals. Algae for abalone is characterised by low lipid and high carbohydrate content

(Viera et al., 2005). Range of lipid requirements from 3%–5%, protein content ranged from 20%–35% while other minerals such as calcium and phosphorus in artificial feed are only needed in small amounts, 0.5% of calcium in diets and 0.7% of phosphorus in the diet can improve the growth rate of abalone. Although there is no information on vitamin supplements in the diet, it is suggested that natural foods suffice (Viera et al., 2005). Therefore, it is crucial to understand the cultivation techniques of these algae so that farmers can produce seaweed crops throughout the year for the abalone industry.

Other Factors

One of the keys to the success of abalone farming is reliable and reproducible spawning, which results in high-quality larvae for grow-out (Nguyen et al., 2022). Therefore, the availability of high-quality seeds is critical to the sustainability of the long-term abalone aquaculture industry. However, the post-larvae stage becomes a main problem in many countries as in this phase, the larvae undergo a change in dietary patterns from zooplankton to periphyton (Grandiosa, 2020). In addition, in abalone hatcheries that are typically located distant from grow-out farms and restocking regions, abalone transport is needed because a higher rate of mortality occurs during the transport of live juveniles. Therefore, this issue needs to be addressed to promote effective aquaculture of abalones. Furthermore, the main remaining hurdle in abalone aquaculture is the slow growth rate of abalone (Nguyen et al., 2022).

CONCLUSION AND FUTURE RECOMMENDATIONS IN AQUACULTURE

Abalone farming and culture have developed rapidly and have gained so much popularity in Southeast Asian countries, especially in Sabah (Malaysia), Southeast Sulawesi (Indonesia), Iloilo (Philippines), Khanh Hoa (Vietnam) and also popular cultured in Thailand waters. Many fundamental studies still have to be resolved in the abalone industry, where there is still a lack of data on population status, species availability and distribution, and research on the optimisation of abalone culture. At its current state of development, the aquaculture of abalone should focus on improving their survival and growth by optimising various culture parameters, such as stocking density, water depth in net cage, water stability, water temperature and photoperiod, pH, diet and different shelter types. In addition, the success of abalone seed production greatly influences its viability for commercial production and wild population restocking programmes.

Although abalone seed production is feasible in most countries, further optimisation of the culture parameters will enhance the survival and overall production output, as most physical parameters are region-specific. Furthermore, future research on the potential use of land-based grow-out production will further shorten the production time of abalones as culture conditions can be monitored and controlled compared to the common open sea culture system. Various genomic selection programs for abalone can also be introduced to select desirable traits selectively. For example, the genome-wide association studies (GWAS) approach was used to identify single nucleotide polymorphisms (SNPs) and candidate genes related to heat tolerance, paving the way for selective breeding programs of abalone that can tolerate future climate scenarios. Similarly, other traits, such as fast growth, high disease resistance, and high fecundity, can be selected for trait improvement of abalone.

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REFERENCES

Amin, M., Bolch, C. J., Adams, M. B., & Burke, C. M. (2020). Growth enhancement of tropical abalone, *Haliotis asinina* L, through probiotic supplementation. *Aquaculture International*, *28*, 463-75. https://doi.org/10.1007/s10499-019-00473-4

Apisawetakan, S., Thongkukiatkul, A., Wanichanon, C., Linthong, V., Kruatrachue, M., Upatham, E., Poomthong, T., & Sobhon, P. (1997). The gametogenic processes in a tropical abalone, *Haliotis asinina* Linnaeus. *Journal of the Scientific Society, 23,* 225-240. https://doi.org/10.2306/scienceasia1513-1874.1997.23.225

Ardi, I., Setiadi, E., & Pranowo, W. S. (2020). The grow-out of abalone (*Haliotis squamata*) at different shelter shape on growth and survival and its marine environmental influences at Lembongan Bay coastal waters. In *IOP Conference Series: Earth and Environmental Science* (Vol. 441, p. 012001). IOP Publishing. https://doi.org/10.1088/1755-1315/441/1/012001

Avendaño-Herrera, R. E., & Riquelme, C. E. (2007). Production of a diatom-bacteria biofilm in a photobioreactor for aquaculture applications. *Aquacultural Engineering*, *36*(2), 97-104. https://doi.org/10.1016/j.aquaeng.2006.08.001

Bansemer, M. S., Qin, J. G., Harris, J. O., Howarth, G. S., & Stone, D. A. J. (2016). Nutritional requirements and use of macroalgae as ingredients in abalone feed. *Reviews in Aquaculture*, *8*(2), 121-135. https://doi.org/10.1111/raq.12085

Bautista-Teruel, M. N., Fermin, A. C., & Koshio, S. S. (2003). Diet development and evaluation for juvenile abalone, *Haliotis asinina*: Animal and plant protein sources. *Aquaculture*, *219*(1-4), 645-653. https://doi.org/10.1016/S0044-8486(02)00410-6

Cai, J., Han, Y., & Wang, Z. (2006). Isolation of *Vibrio parahaemolyticus* from abalone (*Haliotis diversicolor supertexta* L.) postlarvae associated with mass mortalities. *Aquaculture*, *257*(1-4), 161-166. https://doi.org/10.1016/j.aquaculture.2006.03.007

Capinpin, J. E. C., Parreno, S. C., & Abalos, R. S. (2015). Growth of abalone *Haliotis asinina* fed with *Hydropuntia edulis*, singly or in combination with other red algae in sea cages in Tondol, Anda, Pangasinan, Northern Philippines. *Philippine Journal of Science*, *144*, 43-49.

Chieu, H. D., Phuong, L. D., Duy, D. A., Tuan, B. M., & Thoa, N. K. (2016). Aquaculture-based enhancement and restoration of many-colored abalone resources (*Haliotis diversicolor* Reeve, 1846) in Bach Long VI national marine protected area, Vietnam. In H. Kawamura, T. Iwata, Y. Theparoonrat, N. Manajit & V. T. Sulit (Eds.), *Consolidating the strategies for fishery resources enhancement in Southeast Asia* (pp. 174-176). SEAFDEC Publications. http://repository.seafdec.or.th/handle/20.500.12067/718

Cook, P. A., & Gordon, H. R. (2010). World abalone supply, markets, and pricing. *Journal of Shellfish Research*, *29*(3), 569-571. https://doi.org/10.2983/035.029.0303

Daume, S. (2006). The roles of bacteria and micro and macro algae in abalone aquaculture: A review. *Journal of Shellfish Research*, *25*, 151-157. https://doi.org/10.2983/0730-8000(2006)25[151:TROBAM]2.0.CO;2

De Zoysa, M. (2013). Nutritional value, bioactive compounds, and health-promoting properties of abalone. *Marine Nutraceuticals: Prospects and Perspectives*, *57*, 57-68. https://doi.org/10.1201/b13904-11

Eny, D., & Setyono, D. (2007). *Prospek usaha budidaya kekerangan di Indonesia* [Prospects for shellfish cultivation business in Indonesia]. *Oseana*, *32*, 33-38.

Fermin, A. C., & Buen, S. M. A. (2001). Grow-out culture of tropical abalone, *Haliotis asinina* (Linnaeus) in suspended mesh cages with different shelter surface areas. *Aquaculture International*, *9*(6), 499-508. https://doi.org/10.1023/A:1020535301193

Gallardo, W. G., & Buen S. M. A. (2003). Evaluation of mucus, *Navicula*, and mixed diatoms as larval settlement inducers for the tropical abalone *Haliotis asinina*. *Aquaculture*, *221*(1-4), 357-364. https://doi.org/10.1016/S0044-8486(03)00121-2

Gallardo, W. G., & Salayo, N. D. (2003). Abalone culture: A new business opportunity. *SEAFDEC ASIAN Aquaculture, 25*(3), 25-28.

Gamble, L. H. (2017). Feasting, ritual practices, social memory, and persistent places: New interpretations of shell mounds in southern California. *American Antiquity*, *82*(3), 427-451. https://doi.org/10.1017/aaq.2017.5

Ganmanee, M., Sirirustananun, N., & Jarayabhand, P. (2010). Energy budget of the Thai abalone *Haliotis asinina* reared in a semiclosed recirculating land-based system. *Journal of Shellfish Research*, *29*(3), 637-642. https://doi.org/10.2983/035.029.0312

Gao, X., Zhang, M., Luo, X., You, W., & Ke, C. (2023). Transitions, challenges and trends in China's abalone culture industry. *Reviews in Aquaculture, 15*(4), 1274-1293. https://doi.org/10.1111/raq.12769

Geiger, D. L., & Poppe, G. T. (2000). *A conchological iconography: Family Haliotidae*. Conchbooks. https://www.vetigastropoda.com/abstracts/iconography/index.html

Giri, I. N. A., Sutarmat, T., Yudha, H. T., Rusdi, I. & Susanto, B. (2014). Grow-out of abalone *Haliotis squamata* in floating cages fed different proportions of seaweed and with reduction of stocking density. *Indonesian Aquaculture Journal*, *9*(1), 15-21.

Grandiosa, R. (2020). Increasing awareness of abalone culture to support sustainable aquaculture in Indonesia. *Global Scientific Journal*, *8*(6), 315-321.

Hadijah, H. (2017). Effect of natural feed on feed consumption level and feed conversion ratio of tropical abalone *Haliotis asinina* on sea cage. *Applied Mechanics and Materials*, *862*, 121-126. https://doi.org/10.4028/www.scientific.net/AMM.862.121

Hadijah, H., Mardiana, M., Indrawati, E., Budi, S., & Zainuddin, Z. (2021). The use of artificial feed in *Haliotis squamata* farming in submerged cage culture system at Lae-Lae island, Makassar. *Revista Ambiente & Água*, *16*(4), 1-12. https://doi.org/10.4136/ambi-agua.2719

Hamka, I. J. E., & Shearer, D. (2009). *Abalone industry enhancement in eastern Indonesia*. Australian Centre for International Agricultural Research. https://www.aciar.gov.au/sites/default/files/2021-07/C2007102_abalone_industry_enhancement_eastern_indonesia_1.pdf

Hamzah, M. S., Dwiono, S. A. P., & Hafid, S. (2012). Growth and survival of tropical abalone *Haliotis asinina* seed in concrete tanks at different stocking density. *Jurnal Ilmu dan Teknologi Kelautan Tropis*, *4*(2), 191-197. https://doi.org/10.29244/jitkt.v4i2.7781

Handlinger, J., Carson, J., Donachie, L. L. Gabor., & D. Taylor (2005). Bacterial infection in Tasmanian farmed abalone: Causes, pathology, farm factors and control options. In P. Walker, R. Lester & M. G. Bondad-Reantaso (Eds.), *Diseases in Asian aquaculture* (pp. 289-299). Asian Fisheries Society. https://www.fhs-afs.net/daa_v_files/Chapter5_Diseases_of_Molluscs/Bacterial%20Infection%20in%20Tasmanian.pdf

Heasman, M., & Savva, N. (2007). *Manual for intensive hatchery production of abalone.* NSW Department of Primary Industries. https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0013/222331/Manual-for-intensive-hatchery-production-of-abalone-section1.pdf

Hernández-Casas, S., Seijo, J. C., Beltrán-Morales, L. F., Hernández-Flores, Á., Arreguín-Sánchez, F., & Ponce-Díaz, G. (2023). Analysis of supply and demand in the international market of major abalone fisheries and aquaculture production. *Marine Policy*, *148*, 1-9. https://doi.org/10.1016/j.marpol.2022.105405

Huang, W.-B., & Hseu, J.-R. (2010). Changes in growth characteristics of the small abalone *Haliotis diversicolor* (Reeve, 1846) after one decade in a closed culture system: A comparison with wild populations. *Fisheries Science Research*, *76*, 131-137. https://doi.org/10.1007/s12562-009-0190-1

Huchette, S. M., Koh, C. S., & Day, R. W. (2003). Growth of juvenile blacklip abalone (*Haliotis rubra*) in aquaculture tanks: Effects of density and ammonia. *Aquaculture*, *219*(1-4), 457-470. https://doi.org/10.1016/S0044-8486(02)00627-0

Hwang, E. K., Hwang, I. K., Park, E. J., Gong, Y. G., & Park, C. S. (2014). Development and cultivation of F2 hybrid between *Undariopsis peterseniana* and *Undaria pinnatifida* for abalone feed and commercial mariculture in Korea. *Journal of Applied Phycology*, *26*, 742-752. https://doi.org/10.1007/s10811-013-0164-7

Istiqomah, I., & Isnansetyo, A. (2020). Review vibriosis management in Indonesian marine fish farming. In *The 3[rd] International Symposium on Marine and Fisheries Research* (p. 01001). EDP Sciences. https://doi.org/10.1051/e3sconf/202014701001

Jarayabhand, P., Kruiroongroj, W., & Chaisanit, C. (2010). Effects of stocking density on growth performance of Thai abalone, Haliotis asinina, Linnaeus 1758, reared under a semiclosed recirculating land-based system. Journal of Shellfish Research, 29(3), 593-597. https://doi.org/10.2983/035.029.0307

Jarayabhand, P., & Paphavasit, N. (1996). A review of the culture of tropical abalone with special reference to Thailand. *Aquaculture*, *140*, 159-168. https://doi.org/10.1016/0044-8486(95)01194-3

Jardillier, E., Rousseau, M., Gendron-Badou, A., Fröhlich, F., Smith, D. C., Martin, M., Helléouet, M. N., Huchette, S., Doumenc, D., & Auzoux-Bordenave, S. (2008). A morphological and structural study of the larval shell from the abalone *Haliotis tuberculata*. *Marine Biology*, *154*(4), 735-744. https://doi.org/10.1007/s00227-008-0966-3

Jumah, Y. U., Traifalgar, R. F., Jumah, D. S., Reyes, L.R., & Mero, F. F. (2016). Feeding rate and sexes affect gonad growth of donkey ear abalone *Haliotis asinina* Linnaeus, 1758. *Animal Biology & Animal Husbandry*, *8*(1), 10-14.

Kamaishi, T., Miwa, S., Goto, E., Matsuyama, T., & Oseko, N. (2010). Mass mortality of giant abalone *Haliotis gigantea* caused by a *Francisella sp.* bacterium. *Diseases of Aquatic Organisms*, *89*, 145-154. https://doi.org/10.3354/dao02188

Kua, B. C., Ramly, R., Devakie, M. N., Groman, D., & Berthe, C. J. F. (2011). Investigating a mortality in hatchery cultured tropical abalone, *Haliotis asinina* Linnaeus, 1758 in Malaysia. *Disease Asian Aquaculture*, *7*, 103-110.

Lebata-Ramos, M. J. H. (2018). *Grow-out culture of abalone in small islands and/or community. Terminal Report: National Abalone R&D Program.* Southeast Asian Fisheries Development Center.

Lebata-Ramos, M. J. H., Doyola-Solis, E. F. C., Abrogueña, J. B. R., Ogata, H., Sumbing, J. G., & Sibonga, R. C. (2013). Evaluation of post-release behavior, recapture, and growth rates of hatchery-reared abalone *Haliotis asinina* released in Sagay Marine Reserve, Philippines. *Reviews in Fisheries Science*, *21*(3-4), 433-440. https://doi.org/10.1080/10641262.2013.836445

Lebata-Ramos, M. J. H., Hazel, J., & Solis, E. F. D. (2021). Can *Ulva reticulata* replace *Gracilariopsis heteroclada* as natural food for the abalone *Haliotis asinina*? *Journal of Applied Phycology*, *33*(3), 1869-1872. https://doi.org/10.1007/s10811-021-02407-1

Li, Q., Lu, J., Chang, Y., Shen, G., & Feng, J. (2022). Effect of different cooking methods on nutritional intake and different storage treatments on nutritional losses of abalone. *Food Chemistry*, *377*, 1-11. https://doi.org/10.1016/j.foodchem.2022.132047

Lloyd, M. J., & Bates, A. E. (2008). Influence of density-dependent food consumption, foraging and stacking behaviour on the growth rate of the Northern abalone, *Haliotis kamtschatkana*. *Aquaculture*, *277*(1-2), 24-29. https://doi.org/10.1016/j.aquaculture.2008.01.039

Mabuhay-Omar, J. A., Cayabo, G. D. B., & Creencia, L. A. (2021). Bacteriological quality of cage-cultured abalone *Haliotis asinina*. *Aquaculture Research*, *4*(2), 151-159. https://doi.org/10.3153/AR21012

Masuda, R., & Tsukamoto, K. (1998). Stock enhancement in Japan: Review and perspective. *Bulletin of Marine Science*, *62*(2), 337-358.

Maulidya, K. D., Wiradana, P. A., Putranto, T. W. C., & Soegianto, A. (2021). Abalone (*Haliotis squamata*) enlargement technique using a floating net cage method as a preliminary study of mariculture. *Ecology, Environment and Conservation*, *27*(2), 685-689.

Minh, N. D., & Hong, L. T. (2000). Embryonic, larval and postlarval development of *Haliotis asinina* Linneù 1758 in laboratory condition. *Collection of Marine Research Works*, *10*, 190-194.

Minh, N. D., Petpiroon, S., Jarayabhand, P., Meksumpun, S., & Tunkijjanukij, S. (2010). Growth and survival of abalone, *Haliotis asinina* Linnaeus 1758, reared in suspended plastic cages. *Kasetsart Journal (Natural Science)*, *44*(4), 621-630.

Najmudeen, T. M., & Victor, A. C. C. (2004). Seed production and juvenile rearing of the tropical abalone *Haliotis varia* Linnaeus 1758. *Aquaculture*, *234*, 277-292. https://doi.org/10.1016/j.aquaculture.2003.12.013

Nguyen, T. V., Alfaro, A. C., Mundy, C., Petersen, J., & Ragg, N. L. (2022). Omics research on abalone *(Haliotis* spp.): Current state and perspectives. *Aquaculture*, *547*, 1-15. https://doi.org/10.1016/j.aquaculture.2021.737438

Nguyen, T. V., Qian, Z. J., Ryu, B., Kim, K. N., Kim, D., Kim, Y. M., Jeon, Y. J., Park, W. S., Choi, I. W., Kim, G. H., & Je, J. Y. (2013). Matrix metalloproteinases (MMPs) inhibitory effects of an octameric oligopeptide isolated from abalone *Haliotis discus* hannai. *Food Chemistry*, *141*(1), 503-509. https://doi.org/10.1016/j.foodchem.2013.03.038

Nhan, H. T., Jung, L. H., Ambak, M. A., Watson, G. J., & Siang, H. Y. (2010). Evidence for sexual attraction pheromones released by male tropical donkey's ear abalone (*Haliotis asinina*), (L.). *Invertebrate Reproduction & Development*, *54*(4), 169-176. https://doi.org/10.1080/07924259.2010.9652330

Nicolas, J. L., Basuyaux, O., Mazurie, J., & Thébault, A. (2002). *Vibrio carchariae*, a pathogen of the abalone *Haliotis tuberculata*. *Disease of Aquatic Organisms*, *50*(1), 35-43. https://doi.org/10.3354/dao050035

Nuurai, P., Engsusophon, A., Poomtong, T., Sretarugsa, P., Hanna, P., Sobhon, P., & Wanichanon, C. (2010). Stimulatory effects of egg-laying hormone and gonadotropin-releasing hormone on reproduction of the tropical abalone, *Haliotis asinina* Linnaeus. *Journal of Shellfish Research*, *29*(3), 627-635. https://doi.org/10.2983/035.029.0311

Octaviany, M. J. (2007). Beberapa catatan tentang aspek biologi dan perikanan abalon [Some notes on aspects of abalone biology and fisheries]. *Oseana*, *32*(4), 39-47.

Paul, N. A., De Nys, R., & Steinberg, P. D. (2006). Seaweed-herbivore interactions at a small scale: Direct tests of feeding deterrence by filamentous algae. *Marine Ecology Progress Series*, *323*, 1-9. https://doi.org/10.3354/meps323001

Pitchon, D., Cudennec, B., Huchette, S., Djediat, C., Renault, T., Paillard, C., & Auzoux-Bordenave, S. (2013). Characterization of abalone *Haliotis tuberculate Vibrio harveyi* interactions in gill primary cultures. *Cytotechnology*, *65*, 759-772. http://doi.org/10.1007/s10616-013-9583-1

Prihadi, T. H., Ardi, I., Widiyati, A., & Wiyanto, D. B. (2018). Potency of different seaweeds as diets for developing abalone (*H. squamata*) culture in Nusa Penida Island, Bali. In *2nd Scientific Communication in Fisheries and Marine Sciences* (p. 02004). EDP Sciences. https://doi.org/10.1051/e3sconf/20184702004

Sahetapy, J. M., & Latuihamallo, M. (2014). The growth of abalone (*Haliotis squamata*) in net floating cage at Hulaliu Waters, Central District of Moluccas. *Aquacultura Indonesiana*, *15*, 21-25. https://doi.org/10.21534/ai.v15i1.28

Salayo, N. D., Azuma, T., Castel, R. J., Barrido, R. T., Tormon-West, D. H., & Shibuno, T. (2020). Stock enhancement of abalone, *Haliotis asinina*, in multi-use buffer zone of Sagay Marine Reserve in the Philippines. *Aquaculture*, *523*, 1-10. https://doi.org/10.1016/j.aquaculture.2020.735138

Santiago, C. H. S., & Mabuhay-Omar, J. A. (2019). Isolation and characterization of antimicrobial-producing bacteria from the donkey's ear abalone *Haliotis asinina*. *Journal of Shellfish Research*, *38*(2), 413-416. https://doi.org/10.2983/035.038.0224

Setyono, D. (2005). Abalone (*Haliotis asinina* L): Early juvenile rearing and ongrowing culture. *Oseana, 30*(2), 1-10. https://doi.org/10.14203/mri.v30i0.420

Setyono, D. E. D, & Aswandy, I. (2010). Ongrowing techniques for juvenile donkey ear abalone (*Haliotis asinina*) at Pemenang Waters, North Lombok, Indonesia. *Marine Research in Indonesia*, *35*(2), 15-22. https://doi.org/10.14203/mri.v35i2.473

Shi, L., Hao, G., Chen, J., Ma, S., & Weng, W. (2020). Nutritional evaluation of Japanese abalone (*Haliotis discus hannai* Ino) muscle: Mineral content, amino acid profile and protein digestibility. *International Food Research*, *129*, 1-8. https://doi.org/10.1016/j.foodres.2019.108876

Sososutiksno, C., & Gasperz, J. (2017). Economic and financial feasibility of abalone culture development in Hulaliu village, District of Maluku Tengah, Maluku Province. *Aquaculture, Aquarium, Conservation & Legislation*, *10*(6), 1492-1498.

Stewart, P., Soonklang, N., Stewart, M. J., Wanichanon, C., Hanna, P. J., Poomtong, T., & Sobhon, P. (2008). Larval settlement of the tropical abalone, *Haliotis asinina* Linnaeus, using natural and artificial chemical inducers. *Aquaculture Research*, *39*(11), 1181-1189. https://doi.org/10.1111/j.1365-2109.2008.01982.x

Supriyono, E., Liubana, D. V., Budiardi, T., & Effendi, I. (2020). The addition of calcium oxide with different doses in the recirculation system to improve the abalone *Haliotis squamata* seed production. *Jurnal Akuakultur Indonesia*, *19*(2), 199-206. https://doi.org/10.19027/jai.19.2.199-206

Tangtrongpiros, J., & Chansue, N. (1999*). Use of antibiotics for therapeutic treatment of abdominal swelling disease in donkey's ear abalone (Haliotis asinina).* Food and Agriculture Organization of the United Nations. https://agris.fao.org/search/en/providers/122623/records/6472457153aa8c8963043de1

Thao, N. T., An, C. M., Hai, T. N., Dinh, T. D., & Khanh, L. V. (2020). Reproductive cycle of oval abalone (*Haliotis ovina* Gmelin, 1791) distributed on Nam Du island, Kien Giang province. *Can Tho University Journal of Science*, *5*, 175-83. https://doi.org/10.22144/ctu.jsi.2020.053

Thongrod, S., Tamtin, M., Chairat, C., & Boonyaratpalin, M. (2003). Lipid to carbohydrate ratio in donkey's ear abalone (*Haliotis asinina*, Linne) diets. *Aquaculture*, *225*(1-4), 165-174. https://doi.org/10.1016/S0044-8486(03)00287-4

Tsai, C. L., Shiau, C. Y., & Sung, W. C. (2018). Effects of blanching and refrigerated storage on quality attributes of hybrid abalone (*Haliotidae discus hannai*× *H. diversicolor diversicolor*). *Journal of Food Processing and Preservation*, *42*(5), 1-10. https://doi.org/10.1111/jfpp.13608

Viera, M. P., Pinchetti, J. G., De Viçose, G. C., Bilbao, A., Suárez, S., Haroun, R. J., & Izquierdo, M. S. (2005). Suitability of three red macroalgae as a feed for the abalone *Haliotis tuberculata* coccinea Reeve. *Aquaculture*, *248*(1-4), 75-82. https://doi.org/10.1016/j.aquaculture.2005.03.002

Wang, J., Guo, Z., Feng, J., Liu, G., Xu, L., Chen, B., & Pan, J. (2004). Virus infection in cultured abalone, *Haliotis diversicolor* Reeve in Guangdong Province, China. *Journal of Shellfish Research*, *23*(4), 1163-1169.

Wetchateng, T., Friedman, C. S., Wight, N. A., Lee, P. Y., Teng, P. H., Sriurairattana, S., Wongprasert, K., & Withyachumnarnkul, B. (2010). Withering syndrome in the abalone *Haliotis diversicolor* supertexta. *Disease of Aquatic Organisms*, *90*(1), 69-76. https://doi.org/10.3354/dao02221

Williams, E. A., Craigie, A., Yeates, A., & Degnan, S. M. (2008). Articulated coralline algae of the Genus *Amphiroa* are effective natural inducers of settlement in the tropical abalone *Haliotis asinine. The Biological Bulletin*, *215*, 98-107. https://doi.org/10.2307/25470687

Wiradana, P. A., Yusup, D. S., & Soegianto, A. (2018). Preliminary study of biomonitoring *Eschericia coli* and coliform contamination in abalone (*Haliotis squamata*) cultivation pond in Musi Village, Gerokgak Sub District, Buleleng-Bali. *Aquacultura Indonesiana*, *20*(1), 32-40. http://dx.doi.org/10.21534/ai.v20i1.143

Wood, E. M., Mapait, J. B., Bavoh, E. M., Ng, J. V., & Yusah, H. M. (2015). *Abalone culture and farming in Tun Sakaran Marine Park, Sabah*. Marine Conservation Society. https://lighthouse-foundation.org/Binaries/Binary1063/Abalone-culture-and-farming-in-TSMP-2015.pdf

Wu, F., & Zhang, G. (2016). Pacific abalone farming in China: Recent innovations and challenges. *Journal of Shellfish Research*, *35*, 703-710. https://doi.org/10.2983/035.035.0317

Yasa, N. S., Murwantoko, M., Handayani, N. S., Triastutik, G., & Anshory, L. (2020). Physiological, biochemical and HSP70 and HSP90 gene expression profiles of tropical abalone *Haliotis squamata* in response to *Vibrio alginolyticus* infection. *Indonesian Journal of Biotechnology*, *25*(1), 12-20. https://doi.org/10.22146/ijbiotech.51322