Water Quality Assessment and Monitoring of Closed Rearing System of the Sea Cucumber *Holothuria scabra*

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ABSTRACT Sea cucumbers are an essential fishery resource. Therefore, effective aquaculture methods should be developed to achieve their optimal production. Sea cucumbers are susceptible to various environmental factors, one of which is water quality. Monitoring water quality based on physical and chemical parameters should be useful to the rearing system in aquaculture. In practical use, farmers usually monitor only temperature, salinity, and pH, neglecting the essential role of chemical parameters. This review focuses on and urges the monitoring of physical and chemical parameters. We explored the water quality parameters that may be crucial to the sea cucumber rearing system, including temperature, salinity, pH, dissolved oxygen, ammonia, turbidity, particulate organic matter, total nitrogen, nitrate, nitrite, ammonium, silicate, and phosphate. Furthermore, this paper presents a practical way to monitor the aquaculture or rearing system of sea cucumbers. It is suggested that temperature and salinity are the crucial physical parameters, while the essential chemical parameters are phosphate, nitrate, and ammonia.

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1. INTRODUCTION

Sea cucumbers (Echinodermata: Holothuroidea) are large and abundant members of marine benthic communities. They have important functions as deposit feeders, ingesting sediment to get their nutrients from organic matter, and in so doing decreasing nitrogen and phosphorus in the environment and recycling nutrients back into the food web (Purcell et al. 2016; Li et al. 2013). Sea cucumbers can improve sediment quality, water chemistry, and remove residual feed and feces, and for example, can reduce ammonia in water (Purcell et al. 2016).

Sea cucumbers are an important fishery resource, especially in China, Hongkong, Japan, and Korea (Xia et al. 2012b). They have high protein and bioactive components, such as mucopolysaccharides, chondroitin, and antioxidant compounds (Domínguez-Godino and González-Wangüemert 2018). Nevertheless, in consequence of their commercial value, recently, sea cucumber stocks in their natural environment have been decreasing because of over-exploitation and pollution (Collard et al. 2014).

The best way to resolve the problem of decreasing natural stocks of sea cucumber is aquaculture. This means that effective aquaculture methods should be developed to achieve large production of sea cucumbers. Regarding aquaculture issues, water quality is one crucial requirement in a sea cucumber hatchery and grow-out (Xilin 2004; Asha and Muthiah 2005; Zamora and Jeffs 2012).

Sea cucumbers are susceptible to various environmental factors, including water quality. In a culture system, wa-

ter quality is a fundamental abiotic factor affecting growth and survival. Therefore, it is necessary to control water quality by routine monitoring in order to satisfy the requirements of the sea cucumber. Wang et al. (2007) suggested that maintaining water quality within suitable levels is an important key to sea cucumber culture. Common parameters such as temperature, salinity, pH, dissolved oxygen, ammonia, and turbidity should be maintained (Agudo 2006; Kang et al. 2003; Xilin 2004; Purcell et al. 2006; Li et al. 2015). Other parameters such as total nitrogen (TN), total phosphorus (TP), ammonia nitrogen (NH₄-N) Total ammonia-nitrogen (TAN), nitrite-nitrogen (NO₂⁻-N), nitrate-nitrogen (NO₃⁻-N) and orthophosphate (PO₄³⁻-P) have also been reported to be important for rearing *Apostichopus japonicus* in ponds and its juveniles in concrete tanks (Purcell et al. 2006; Li et al. 2015).

Monitoring water quality based on physical and chemical parameters is therefore useful for rearing in aquaculture. In practical use, farmers usually monitor only temperature, salinity, and pH, neglected the essential roles of chemical parameters. This review urges the use of monitoring of chemical parameters such as dissolved oxygen and nutrients. Furthermore, it lays out a practical method of monitoring sea cucumber aquaculture or rearing systems.

2. REARING SYSTEMS RELIANT ON WATER QUALITY

Sea cucumbers are a relatively new target species for the aquaculture industry. All over the world, over-fishing and habitat destruction have pushed several species' already de-

pleted natural stocks into extinction, particularly those with economic value (Conand 2017, 2018). Aquaculture is a double solution to reducing dependency on natural populations and coping with growing demand. Currently, *A. japonicus* and *Holothuria scabra* are the species with the most advanced culture techniques and primarily produced in aquaculture (Xu et al. 2015; Han et al. 2016; Robinson and Lovatelli 2015). Mass production of juveniles for these two species is possible, as well as some visible technique options for grow-out (Purcell et al. 2012; Zhang et al. 2015). Several potential species such as *Cucumaria frondosa* (Nelson et al. 2012b), *Parastichopus californicus* (Azad et al. 2014), *Holothuria polii* (Rakaj et al. 2019), *Holothuria arguenensis* (Domínguez-Godino and González-Wangüemert 2019), and *Holothuria mammata* (Domínguez-Godino and González-Wangüemert 2018) are still in the early stage of development.

Sea cucumbers are mostly cultured in an extensive manner (Eriksson et al. 2012) because most of these group members are benthic faunas that live on substrates. Culture density is directly related to this characteristic. Species with the ability to climb and attach to vertical substrates, such as *A. japonicus*, can be cultured in higher density by providing an extra substrate and additional feed (Han et al. 2016). Contrarily, sea cucumbers that live on the top of sediment, particularly species with burying behavior such as *H. scabra* (Purcell 2010), can only be kept in lower density because of limitations in surface area and the carrying capacity to support sea cucumber growth. Diet types, as well as feeding behavior, are other vital factors that determine the culture system. Most sea cucumbers are benthic feeders, feeding on detritus and microbiota (MacTavish et al. 2012), and some species are suspension feeders (Nelson et al. 2012a). As such, biological characteristics are a crucial consideration in developing culture techniques. Currently, there are three conventional rearing methods of sea cucumbers: tank, pond, and sea farming.

The tank system is used in hatchery, early nursery, and broodstock rearing (Agudo 2006; Zhang et al. 2015). There are different types of sea cucumber tanks; for example, concrete, fiberglass, glass, plastic, and wood with coating or lining. The main advantage of a tank culture is that the system is relatively controlled, so water quality can be adjusted to the biota requirements, making it suitable for sensitive processes such as broodstock maturation and spawning, larval rearing, or a juvenile nursery. A tank culture system is usually equipped with a water supply and filtration system, aeration or oxygenation system, and temperature control system (Zhang et al. 2015). To maintain water quality, the most simple tank culture adopts a flow through or partial water exchange approach, while the more advanced ones adopt a recirculating aquaculture system. For the grow-out phase, high investment in the tank culture system makes it generally not economically feasible for the low-density culture of sea cucumbers.

The pond system is a reasonable choice for a nursery and grow-out of sea cucumbers and is widely used for *A. japonicus* (Zhang et al. 2015; Han et al. 2016) and *H. scabra* (Purcell 2004; Agudo 2012; Duy 2012; Purcell et al. 2012; Purcell and Wu 2017). Suitable ponds are those located at the lower tide level for the convenience of water exchange and must be free of pollution or contamination (Han et al. 2016). Pond conditions should meet sea cucumber species-specific biological requirements, such as water quality (particularly salinity and temperature) and types of substrates. A sandy or sand-muddy bottom is the preferred sediment type for sea cucumber aquaculture (Han

et al. 2016). For *A. japonicus*, providing a suitably hard structure as the substrate is necessary (Han et al. 2016), to provide shelter and facilitate the development of benthic diatoms as a high-quality food source (Zhang et al. 2015). Sea cucumbers need very low frequency applications of artificial feed, and natural food in the form of suspended organic matter brought by water exchange (Han et al. 2016), or organic waste matter in ponds (Purcell et al. 2012), can be adequate. Seasonal declines in seawater temperatures in ponds are a problem for the growth of sandfish at high latitudes (Agudo 2012; Bell et al. 2007), while the stratification of water, salinity fluctuation, and proliferation of filamentous benthic algae is a crucial problem for farmers in tropical regions (Agudo 2006; Pitt and Duy 2004; Agudo 2012). Sea cucumber pond culture generally is extensive; more research is needed to increase this system's productivity. Purcell et al. (2012) have suggested that stocking densities, water exchange, and feeding are determining factors.

Sea farming is another alternative system for sea cucumber aquaculture. This system allows coastal communities to farm sea cucumbers using simple tools and techniques. Some sea cucumbers can be grown in suspended cages; for example, *A. japonicus* (Zhang et al. 2015), *C. frondosa* (Nelson et al. 2012a), and *P. californicus* (Hannah et al. 2013). Suspended cages are suitable for well-protected inner bays where waves are small and water is clear, nutrient-rich, and frequently turned over (Zhang et al. 2015). The optimal stocking densities for *A. japonicus* in a suspended cage has been determined to be 22.3 ind.m⁻² for feed-supplemented pens and 14.1 ind.m⁻² for non-feed-supplemented pens (Qin et al. 2009). Another sea farming method is sea pen or cage culture, which has been used in *H. scabra* grow-out (Juinio-Meñez et al. 2014; Dumalan et al. 2019). Ceccarelli et al. (2018) reported that the survival and growth rate of *H. scabra* was significantly higher at shallow depths with intermediate seagrass cover and high organic carbon content of sediments. To harvest *H. scabra* at the marketable size (>300 g.ind⁻¹) over a 6 to 8-month grow-out period in sea pens, they should be stocked with larger juveniles (>50 g) and standing biomass should be kept below 300 g.m⁻² (Juinio-Meñez et al. 2014). In addition to sea farming, the sea-reaching approach is almost similar, the main difference being that the sea cucumbers are deployed in a relatively large area of its natural habitat. In contrast to the tank and pond systems, environmental conditions in sea farming are almost entirely out of farmers' control, and therefore site selection is essential (Hair et al. 2016; Ceccarelli et al. 2018). Predation seems to be the only factor that can be managed in sea farming; however, this is also the major disadvantage of sea farming compared with land-based farming. The main known predators of sea cucumbers in the wild are carnivorous fishes, marine mammals, birds, sea stars, sea urchins, crabs, and gastropods. In *H. scabra* farming, *Thalamita crenata* has been reported as a major predator (Eeckhaut et al. 2020), while in *A. japonicus*, the sea star *Asterina* sp. has been reported to often cause excessive mortality (Yu et al. 2015). Predation can be prevented by selecting a location with lower predator abundance, providing shelter (Yu et al. 2015), using durable cage materials, and manually eradicating predators.

In addition to monoculture, there is growing interest worldwide in combining sea cucumbers with other species from different trophic levels to explore sea cucumbers' ability to utilize organic matter produced by the aquaculture industry (Zamora et al. 2018). The approaches are varied, from simple co-culture to combining sea cucumbers in a

more complex integrated multitrophic aquaculture (IMTA) system. The most common approach for sea cucumber polyculture is by placing sea cucumbers in cages underneath a cultured species such as finfish, crustaceans, or shellfish (Zamora et al. 2018). Various studies reported a positive impact of sea cucumber integration with different species; for example, *H. scabra* with the milkfish *Chanos chanos*, pompano *Trachinotus blochii*, and Asian sea bass *Lates calcarifer* (Mills et al. 2012); and Babylon snail *Babylonia areolate* and sea grape *Caulerpa lentillifera* (Dobson et al. 2020). Other sea cucumbers have also reportedly demonstrated their potential in reducing organic waste from aquaculture systems; these are *A. japonicus* (Qi et al. 2013; Yu et al. 2014; Yuan et al. 2015), *C. frondosa* (Nelson et al. 2012a), *P. californicus* (Hannah et al. 2013), *H. forskali* (MacDonald et al. 2013), and *H. tubulosa* (Neofitou et al. 2019). However, sea cucumber co-culture is not always successful. Bell et al. (2007) reported that the growth and survival of *H. scabra* is poor when combined with the shrimp *Litopenaeus stylirostris*. To prevent failures in both co-culture and IMTA, future research should focus on species compatibility, by testing different combinations of possibilities over a range of potential species, including finfish, crustacea, shellfish, and seaweed with different animal sizes and stocking density (Purcell et al. 2012). Meanwhile, more information is needed related to the biological characteristics of sea cucumbers and co-culture species, bioremediation capacity, as well as waste quality and production.

3. WIDELY KNOWN UP TO THE PRESENT: THE EFFECT OF TEMPERATURE, SALINITY, AND PH

There are many factors affecting the growth of sea cucumbers. Environmental conditions play a role in sea cucumber development. Monitoring of environmental conditions is important because larvae and juveniles are sensitive to environmental changes. One ecological factor that influences growth and physiological processes in aquatic eurythmics is water temperature (Ji et al. 2008). Dong et al. (2006) noted that fluctuating temperatures within the range of ecological tolerance affect the growth of sea cucumbers.

Water temperature also affects the feeding behavior, metabolism, and growth of sea cucumbers. Sea cucumbers have a wide water temperature range, from 10 to 32.8°C (Asha and Muthiah 2005; Chen 2003; Yu et al. 2015). For subtropical species, the specific growth rates of sea cucumbers cultured at 26°C was lower than those cultured at 18°C, which may be due to the depression of feeding and metabolism of the sea cucumbers induced by the higher temperature (Yu et al. 2015). Chen (2003) reported that a suitable environment for sea cucumbers, in terms of salinity, should be over 27 ppt, while the optimum temperature for growth is 10–17°C, although juveniles can maintain high growth rates at temperatures of 24–25°C or higher, which are typical of tropical regions. Both constant and diel fluctuating temperatures influence growth, proximate body composition, and oxygen consumption in juvenile *A. japonicus*. The maximum SGR was found to be 1.48% day⁻¹ at 16–18°C and significantly declined at 24°C (Dong et al. 2006). Ji et al. (2008) reported that one strategy of *A. japonicus* to adapt in high temperatures is aestivation; this condition occurred when this sea cucumber was maintained at 26°C. Growth of juveniles of *A. japonicus* in size, from 2.00 to 2.51 g, has optimum thermal amplitudes in average temperatures of 15 and 18°C (Dong et al. 2006). Zamora and Jeffs (2012) experimented with four seawater temperatures

(15, 18, 21, and 24°C) for 105 days using juvenile *Australostichopus mollis*. The results showed that the feeding behavior, physiology, and growth of the juveniles were greatly affected by seawater temperatures in the range of 15–24°C. The metabolism, feeding behavior, growth, and survival of sea cucumbers is thus affected by seawater temperature, because they are ectothermic animals with a body temperature dependent on an external source, which in turn modulates most of their biochemical and physiological processes (Zamora and Jeffs (2012). A better understanding of how this species responds to changes in seawater temperature will be useful for their aquaculture and stock enhancement.

Asha and Muthiah (2005) observed that temperature, salinity, and pH all impact the growth of sea cucumbers. In 2005, they researched this impact on the growth and survival of the larvae of *H. spinifera* (48 h post-fertilization). The larvae were reared for 12 days at temperatures of 20, 25, 28, and 32.8°C; salinities of 15, 20, 25, 30, 35, and 40 ppt; and pH of 6.5, 7.0, 7.5, 7.8, 8.0, 8.5, and 9.0. The highest survival and growth rate and fastest development of the larvae indicated that a water temperature of 28–32.8°C, salinity of 35 ppt, and pH of 7.8 were the most suitable rearing conditions (Asha and Muthiah 2005).

Salinity is one of the crucial abiotic and physiological factors that influence the growth and survival of sea cucumbers (Hu et al. 2010; Sembiring et al. 2019). The sea cucumber, as a stenohaline and osmoconforming organism, has a low level of tolerance to salinity alteration (Sembiring et al. 2019). Stress in salinity can cause multiple effects in sea cucumbers, such as damage and degradation of their morphological and histological structures, and could also impact ion homeostasis, Na⁺/K⁺-ATPase (Geng et al. 2016). Salinity and temperature have been found to be important factors in determining the distribution of *A. japonicus*. Here, the salinity was between 24.2 and 34.6 psu and the temperature was around 24.5°C (Liu 2014). Another study reported that the salinity associated with the highest growth rate in pond-cultured *A. japonicus* was between 27 and 31.5 psu in optimal temperatures (Yuan et al. 2010). Liu et al. (2013), in a study on *A. japonicus*, noted that seawater conditions were maintained at pH 7.8–8.2 and salinity of 30–32 ppt. Li and Li (2010) also reported that the optimum temperature and salinity to ensure the highest survival and growth value in the early development of *A. japonicus* is between 21 and 24°C and 30‰, respectively. Zhang et al. (2015), meanwhile, found that the growth of juvenile *A. japonicus* was higher when the temperature was constant instead of fluctuating. When levels are above the optimum salinity, it will affect the development of larvae, causing defectiveness or death.

The environmental conditions for rearing *H. scabra* larvae include an optimum temperature of 27–29°C, dissolved oxygen level of 5–6 ml/L, and alkaline pH of 7.5–8.5. The pH value is highly important to the growth of larvae; when it is above 9.0 and below 6.0, growth is impaired (James 2004).

Sithisak et al. (2013) carried out a study involving a co-culture of *H. scabra* and red tilapia. In this research, a suitable environmental condition was required, which comprised a dissolved oxygen level of 5.0–5.5 ppm, pH of 7.5–8.0, alkalinity of 140–160 ppm, total ammonia nitrogen of <0.5 ppm, total nitrite of <0.2 ppm, and salinity of 28–30 ppt. The authors found that the growth and survival of *H. scabra* was higher when co-cultured with red tilapia than when cultured alone. In addition, monitoring of the concentration of nitrate was necessary. In this regard, Tuwo et al. (2012) have highlighted that the most suitable concentration of nitrate for *H. scabra* growth ranges from 0.02 to 0.08 ppm.

4. PARTICULATE ORGANIC MATTER AND NUTRIENT RELEVANCE TO THE MONITORING OF WATER QUALITY IN REARING SYSTEMS

Aquacultures produce high concentrations of organic matter as well as inorganic nutrients, antibiotics, and uneaten food pellets which can produce problems of eutrophication (Sadeghi-Nassaj et al. 2018). This problem can be resolved by sea cucumbers because they can improve water transparency and can bioremediate sediment by consuming particulate organic matter (POM) (Sadeghi-Nassaj et al. 2018; Watanabe et al. 2012). This mechanism reduces the concentration of colored dissolved organic matter derived from POM dis-aggregation or to the direct assimilation of dissolved compounds of low molecular weight as chromophoric amino acids (Sadeghi-Nassaj et al. 2018). Sea cucumbers tend to modify their foraging behavior and digestive capabilities to optimize the intake of nutrients from the organic component in sediments. A study by Namukose et al. (2016) showed that both total organic matter and total organic carbon decreased in the experimental period, with the influencing factor being the number of sea cucumbers (stocking density). Sediment reworking and organic matter uptake could depend on individual numbers and sizes, food availability, and local conditions.

Ammonia-nitrogen is an indicator for evaluating the nutritional quality of feed because it indicates how much protein is deposited in the body (Xia et al. 2012a). The main sources of ammonia in breeding tanks are the metabolites of the larvae, excess food, and decomposing organisms. The accumulation of ammonia in concentrations above 0.5 ppm can be harmful for the larvae. Otherwise, larvae can develop normally with ammonium-nitrogen levels in the range of 0.07 to 0.43 ppm of water (James 2004).

5. HOLOTHURIA SCABRA REARING SYSTEM: STUDY CASE OF WATER QUALITY MONITORING

The study case was conducted in the growth experiment of *H. scabra* in correlation with the assimilation rate of organic carbon. We set several diet treatments for juveniles of *H. scabra*, namely seagrass leaves (*Enhalus acoroides*), cow feces, and rice bran. The three sea cucumber juveniles originated from a natural environment (Kayangan and Sekotong) and pond. The locus was in Lombok Island, Indonesia. The experiment was conducted up to 65 days and the water quality monitored included pH, temperature, salinity, nitrate, ortho-phosphate, and silicate.

Water temperature in the experiment tanks varied with time for all feeding treatments (Figure 1). Since it was a closed rearing system, this fluctuation was greatly influ-

enced by the air temperature. Water temperature does not affect the survival of tropical sandfish but it does affect their juvenile growth (Han et al. 2016). Temperature during the experiment ranged between 23 and 26°C. According to Kühnhold et al. (2019), those temperatures are out of the range suitable for optimum growth of *H. scabra* (sandfish), which requires a temperature of 27–29°C. However, Yao et al. and Lavitra et al. in Han et al. (2016) mentioned that tropical sandfish may grow optimally at temperatures between 20 and 30°C with the fastest rate at 25°C.

Likewise, salinity during the experiment was out of the range for optimal sandfish growth according to Sithisak et al. (2013), ranging 36–37 ppt, whereas the recommended range of salinity for optimum growth of sandfish is 28–30 ppt. Unlike temperature and salinity, the pH range during the experiment generally met the recommended pH range for optimum growth of sandfish, at 7.5–8.5 (James 2004; Sithisak et al. 2013). In addition, the pH tended to increase with experimental duration. This phenomenon was similar to a previous study conducted by Gangadhar et al. (2017).

Dissolved silicate (DSi) dynamics during *H. scabra* rearing were almost similar for all feed treatments except for that with rice bran (Figure 2). DSi concentrations after several days of the experiment tended to decrease and they became steady for the rest of the experimental days. In contrast, after several days of rice bran feeding, the DSi concentration increased and then flattened for the remaining days of the experiment. The decrease of DSi concentrations was due to silicate uptake by siliceous phytoplankton. On the other hand, the increase in DSi concentration was due to source input from the rice bran feed, since rice bran is rich in silica (Kalapathy et al. 2000). The variability in DSi concentration during the rice bran feed treatment might be caused by different rates of rice bran digestive processing by the sandfish. Silica in rice bran is typically not soluble in water. By consuming silicate-rich rice bran and defecating it, *H. scabra* may convert silica through its digestive system from an insoluble form into a soluble form (DSi).

Nitrate dynamics during the experiment showed a decreasing trend with time. This pattern was observed in almost all treatments except for that with cow dung, where nitrate tended to slightly increase. Nitrate uptake by phytoplankton was likely to be the main cause of the drop in nitrate level, whereas cow dung feeding was the nitrogen source leveling up nitrate concentration. Cow dung feeding is a common practice in aquaculture in order to serve food for fish either directly or indirectly (Knud-Hansen and Clair 1998). In the case of sandfish, cow dung indirectly serves food since it may boost the growth of phytoplankton and zooplankton. Sea cucumbers including *H. scabra* are effective consumers of phytoplankton and zooplankton

FIGURE 1. (a) Monitored temperature, (b) salinity, and (c) pH of culture system during the experiment.

FIGURE 2. Nutrient parameters of the culture system monitored during the experiment. (a) Silicate, (b), nitrate, (a) ortho-phosphate.

detritus. In addition, sandfish may directly consume cow dung as organic matter (Navarro et al. 2013).

Ortho-phosphate or dissolved inorganic phosphorus (DIP) dynamics were similar to those of DSi for almost all of the treatments. There were almost no significant changes in DIP concentration during the experiment. This lack of variation between treatments and experimental days might have been caused by different levels of DIP sources when the seawater in the rearing tanks was circulated. Notably, the DIP concentration from the rice bran feeding treatment tended to slightly increase with time. This was due to additional phosphorus input from the feed, as rice bran is rich in phosphorus in the phytate form (Bhosale and Vijayalakshmi 2015). This organic substance has low solubility in seawater (Cigala et al. 2010). By digesting rice bran and secreting the waste, sandfish convert insoluble organic phosphorus into inorganic soluble phosphorus (DIP). DIP can immediately be incorporated into sediment, so DIP accumulation in sediment may occur. As a consequence, water circulation does not remove all DIP from the closed rearing system. Conversely, DIP in the sediment can be released back into the water column through diffusion or sediment resuspension, leading to an increased level of DIP in the water.

6. THE CRUCIAL PARAMETER IN WATER QUALITY MONITORING IN MARICULTURE

One water quality parameter that has a direct effect on organisms is temperature. Fluctuating temperatures have a significant impact on biochemical and physio-ecological processes, as well as parameters such as activities of antioxidases and heat shock protein (Hsp) 70 levels, production of reactive oxygen species and denatured proteins, immune capacities, energy for respiration, feeding behaviour, excretion, rates of ingestion, defecation, growth, and carbon and nitrogen budgets (Dong et al. 2006; An et al. 2007; Ji et al. 2008; Wang et al. 2007; An et al. 2009; Yuan et al. 2013). Kühnhold et al. (2017) found that sea water temperature plays an important role in the metabolic activity of *H. scabra* juveniles, including in cellular energy allocation, oxygen consumption, and energy metabolism related to enzyme activities. Similarly, optimal pH stability affects enzyme activity in the body wall of sea cucumbers (Zhu et al. 2009), while salinity affects larvae metamorphosis and early development of juvenile *A. japonicus* (Li and Li 2010).

Water exchange, whether in partial or complete systems, is necessary to maintain water quality in sea cucumber culture. Sea water in rearing tanks needs to be exchanged regularly in order to ensure the desired water quality. In a study by Hu et al. (2010), sea water in *A. japonicus* juvenile rearing tanks was replaced completely every day. Moreover, Liu et al. (2012) exchanged 50% sea water every second day and Agudo (2006) replaced 30% seawater

in larvae tanks. Meanwhile, Li et al. (2015) exchanged 20% sea water daily and monthly in a pond culture. Purcell et al. (2006) replaced 20% sea water in treatment tanks of a *H. scabra* juvenile co-culture with juveniles of the blue shrimp *Litopenaeus stylirostris* (Stimpson).

The rearing system of sea cucumbers has to be considered because of the effect of the crucial water quality parameter. In outdoor systems, both rearing in the pond and sea farming are affected by environmental factors. Maintaining water quality in the pond or sea might be difficult due to the weather, tides, currents, access to a freshwater source, storms, typhoons, or seasons (Hu et al. 2010; Mills et al. 2012; Purcell et al. 2012). Heavy rainfall in ponds may lead to stratification that induce low salinity, high temperatures, and which further increases oxygen demand and compounds depletion (Mills et al. 2012). This extreme condition has occasionally occurred in the bottom of the pond, thus interfering with *H. scabra* as a benthic organism (Agudo 2006). In addition, Li et al. (2015) reported that both total nitrogen and total phosphorus in pond water were not influenced by the feeding treatment, but rather sampling time, while ammonia nitrogen ($\text{NH}_4\text{-N}$) was affected by both sampling time and feeding treatment. Sea cucumber culture ponds are commonly 2–3 m in depth, making them susceptible to changes in environmental conditions (Hu et al. 2010). In pond cultures, sea cucumbers are able to tolerate extreme salinity fluctuations, but function ineffectively in terms of energy spent on growth if outside their optimal salinity range (Yuan et al. 2010). On the other hand, in sea farming, the sea cucumber habitat is influenced by seasonal and daily fluctuations, which create their own extreme changes in water temperatures (Robinson and Pascal 2012; Zamora and Jeffs 2012). Natural sea water temperature has to be the main consideration during site selection, in either pond culture or sea farming (Zamora and Jeffs 2012). Furthermore, in a co-culture system with juvenile *H. scabra* and juvenile *L. stylirostris*, ammonia concentration is the most important parameter to affect *H. scabra* growth; thus soluble nitrogenous wastes of shrimps influence lower growth in sandfish and have a toxic effect (Purcell et al. 2006). Kang et al. (2003) showed in their experiment that a co-culture of *A. japonicus* with the abalone *Haliotis discus hannai* could reduce water quality matter, where the sea cucumber as a deposit feeder can minimize the level of inorganic nitrogen in the water.

Conventionally, from the larval to early juvenile stages, sea cucumbers are reared indoors. Rearing in tanks enables stable control of water quality. Wang et al. (2007) reported that in an indoor culture tank, dissolved oxygen concentration is not a crucial parameter in sea cucumber growth, since this system uses aeration and oxygen saturation, and is consequently stable. Moreover, salinity remained within a narrow range in the recirculation system;

this did not have a negative impact on sea cucumber growth besides the effect of salinity tolerance on the capability of osmoregulation (Wang et al. 2007; Hu et al. 2010). Sea cucumbers were sensitive to fluctuation in ambient temperature (Dong et al. 2006). Constant water temperature in an indoor tank rearing system can be maintained by pumping cold water, employing a heater or thermostat, and using a recirculation pump (Agudo 2006; Dong et al. 2006; An et al. 2009). Agudo (2006) studied how the size of rearing tanks affects temperature, and found that utilizing bigger tanks leads to reducing temperature-induced stress.

7. CONCLUSIONS

We explored the water quality parameters that may be crucial to sea cucumber rearing systems, including temperature, salinity, pH, dissolved oxygen, ammonia, turbidity, particulate organic matter, total nitrogen, nitrate, nitrite, ammonium, silicate, and phosphate. Furthermore, this paper reveals a practical way of monitoring sea cucumber aquacultures or rearing systems. In line with the study case on monitoring a *H. scabra* juvenile rearing system, it has been suggested that temperature and salinity are the crucial physical parameters. Furthermore, the essential chemical parameters are phosphate, nitrate, and ammonia. Dissolved oxygen, particulate organic matter, and pH may be monitored, as well, for a better overview in maintaining the rearing system.

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AUTHORS' CONTRIBUTIONS

All authors are considered to have given equal contributions to the present research.

COMPETING INTERESTS

The authors declare no competing interest.

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