Aquaculture Reports 3 (2016) 67–76

Contents lists available at ScienceDirect

Aquaculture Reports

journal homepage: www.elsevier.com/locate/aqrep

Development of an integrated multi-trophic aquaculture (IMTA) system for tropical marine species in southern cebu, Central Philippines

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ARTICLE INFO

Article history:
Received 5 June 2015
Received in revised form
26 December 2015
Accepted 28 December 2015
Available online 6 January 2016

Keywords:
Donkey
's ear abalone
Extractive species
Tropical IMTA
Water quality

ABSTRACT

This study presents the establishment of an integrated multi-trophic aquaculture (IMTA) system in the tropical open waters of southern Cebu, Philippines using a combination of locally available species, namely donkey's ear abalone (*Haliotis asinina*) as fed species and seaweeds (*Gracilaria heteroclada* and *Eucheuma denticulatum*) as inorganic extractive species. The culture of *Caulerpa lentillifera* as a biofilter did not work in the open sea cultivation system using baskets. Monthly measurements of shell length, width and body weight of the cultured abalones, together with in situ measurements of physicochemical parameters to assess any changes in water quality, mainly nitrate, nitrite, ammonia and phosphate, were conducted over a year period from February 2013 to January 2014 in three designated stations (Abalone, Seaweed and Control Stations) at three different depths (surface, middle and bottom).

Cage culture of abalone side by side with seaweeds in the open sea did not result in any significant water quality disturbance in the area—at least not in the current volume of caged abalones being used. Of the four inorganic compounds monitored in the field, nitrate and ammonia in the Seaweed Station were shown to have relatively lower year-round average values when compared with the Abalone Station, although in the case of nitrate, it was higher in the Control Station compared with the abalone and Seaweed Stations. Although this difference was not significant, it shows the red seaweeds, *G. heteroclada* and *E. denticulatum,* to be functioning as a natural filter for these two nutrients. In contrast, nitrite, and phosphate concentrations were not reduced indicating that the seaweeds were not effective biofilter for these two nutrients.

The two-month old hatchery-bred donkey's ear abalones can grow to a size of 53.8 × 28.2 mm ($L \times W$) and body weight of 37.8 g after a period of 12 months. Any expansion of the farm into a much larger commercial-scale farm will have to be complimented with seaweeds stocked around it if only to mitigate possible build-up of excess inorganic wastes—to serve as both a natural filter and as a source of natural feed. The potential use of an organic extractive species has to be further studied under farm condition to achieve its full potential as an IMTA species.

1. Introduction

More than 60% of the world's population of 6.7 billion is in Asia whose reliance on animal protein comes from fish and other aquatic foods obtained from both capture and captive fisheries (Liao, 2002). Aquaculture contributed 91% of the world's total production in 1999 and will be the only means to meet the increasing demand for seafood to offset the global shortfall of fishery production from capture fisheries (FAO, 2008). Aquaculture production of fish and shellfish has grown by an average of 7.7% per year over the last decade (Gjedrem et al., 2012). However, aquaculture has also been responsible for many of ecosystems failure. Sustainable fishery production is a big challenge of the aquaculture industry especially where there is an extensive use of commercial feeds that, itself, contributes to a much bigger problem in open water systems—i.e., water pollution (Chávez-Crooker and Obreque-Contreras, 2010). This is in addition to the fact that aquaculture has been responsible for the loss of mangrove communities in most of southeast Asia in

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http://dx.doi.org/10.1016/j.aqrep.2015.12.006

the 1970s to 80s, to give way for fish and shrimp production ponds (Primavera, 2005). The increasing popularity of using open sea culture systems for marine fish production is anticipated to intensify the use of commercially formulated feeds. With no intervention so far instituted in this type of culture system in the Philippines, this could pose a potential threat to coastal areas where these activities are mainly concentrated.

In Asia, where aquaculture had its early beginnings, fish farmers use integrated aquaculture commonly for the production of shrimp and milkfish. In the Philippines, the concept of integrated aquaculture is nothing new and has been applied for decades on milkfish–shrimp combination, seaweed–milkfish, shrimp–seaweed, rice–tilapia, tilapia–carp (Palma et al., 2007), fish–duck–pig (Alcover, 2007), etc., which are usually done in pond systems. Open sea culture using a combination of multi-trophic species in the concept of IMTA is a relatively new context for tropical setting such as the Philippines and is worth exploring to harness its potential benefits of being environmentally sustainable. In his review of the developments of global aquaculture, Troell (2009) indicated that only 16% of research so far done on integrated tropical aquaculture, were on open water environments and mostly involving seaweeds.

Integrated multi-trophic aquaculture (IMTA) is an ecosystems approach in mariculture that has been proven to solve sea pollution problems associated with fish culture mainly in temperate waters (Troell, 2009). IMTA system uses marine species that are not only commercially viable, such as salmon, but are also environmentally sustainable, based on the concept that the wastes consisting of uneaten feed, feces and metabolic excretion of one species are a useful input for growth of another species, working in a natural self-cleansing mechanism (Chopin et al., 2001). While it is possible to adopt the IMTA system in the tropical waters using local species, Lander et al. (2013) suggested that site specific practices need to be implemented as it is most likely not possible to develop a universal system for IMTA systems. Two locally available marine organisms were tested—the donkey's ear abalone (*H. asinina*) as the fed species and mixed seaweeds (green *Caulerpa lentillifera* and red *Gracilaria heteroclada* and *Eucheuma denticulatum*) as the extractive components. Donkey's ear abalone grows in coral reefs where there are abundant algae to feed on. Due to overexploitation and habitat degradation, the natural stock of this species is experiencing depletion and necessitates the use of mariculture both for restocking and commercial production (Capinpin, 2013). The red seaweed, *G. heteroclada* (the current identification of this species as *G. manilaensis* by Song et al., 2013 is not used in this study to minimize confusion with those used in earlier studies), known locally as 'gulaman' or 'uwaman', is a preferred food of abalone (Capinpin and Corre, 1996). Other species of this genus are used for the industrial extraction of agar. On the other hand, the green seaweed, *C. lentillifera* ('sea grapes' or 'green caviar'), is a popular seaweed used as fresh salad and traditionally grown in earthen fish ponds in Mactan Island, Cebu.

This paper reports the initial results of establishing an IMTA system of growing donkey's ear abalone in cages in the open sea, side by side seaweeds as both feed and extractive component for inorganic wastes. This arrangement is in stark contrast to that of the conventional aquaculture model which does not consciously integrate extractive species.

2. Methodology

2.1. Establishing the abalone farm into an IMTA culture system

The donkey's ear abalone culture was set up in February 2013 which consisted of a floating platform with a total area of close to 0.25 hectares and floated at a depth range of 5–10 m off the coast of Ronda, Cebu, central Philippines (Fig. 1).

The floating open-sea farm was set up in collaboration with Presito Mariculture Corp. which aimed to create a livelihood opportunity for the coastal community. Two-month old juvenile abalones (2–3 cm shell length) were obtained from a hatchery facility of the Bureau of Fisheries and Aquatic Resources 7 (BFAR 7) in Calape, Bohol. The hatchery-bred animals were brought to Ronda and immediately placed into dark plastic trays at a density of 1000 individuals per tray. The trays were then hanged about two meters below the sea surface under a floating platform designated herewith as the "Abalone Station". Monthly measurements of shell length (SL), width (SW) and body weight (BW) were made on thirty (30) randomly selected individuals using a vernier caliper and a digital balance, respectively. To minimize stress, exposure of the animals to the air was kept to a minimum by returning them immediately to the seawater as soon as measurements were made. After three months (May) the abalones were transferred to larger cages ($L \times W \times H = 50 \times 40 \times 100$ cm) which have five compartments each. Abalones were placed at a density of 200 individuals in each compartment which were reduced to 50 per compartment after a month (June) according to the specification described by Encena et al. (2013). Abalones in each cage were fed with about 200 g of fresh seaweed *G. heteroclada ad libitum* or about every 2–3 days. The seaweed is a preferred diet for *H. asinina* (Capinpin and Corre, 1996).

Daily growth rate (DGR) of abalones is computed using the following formula:

$$\text{Daily growth rate (DGR)} = \frac{[(W_f - W_i)] \times 100}{t}$$

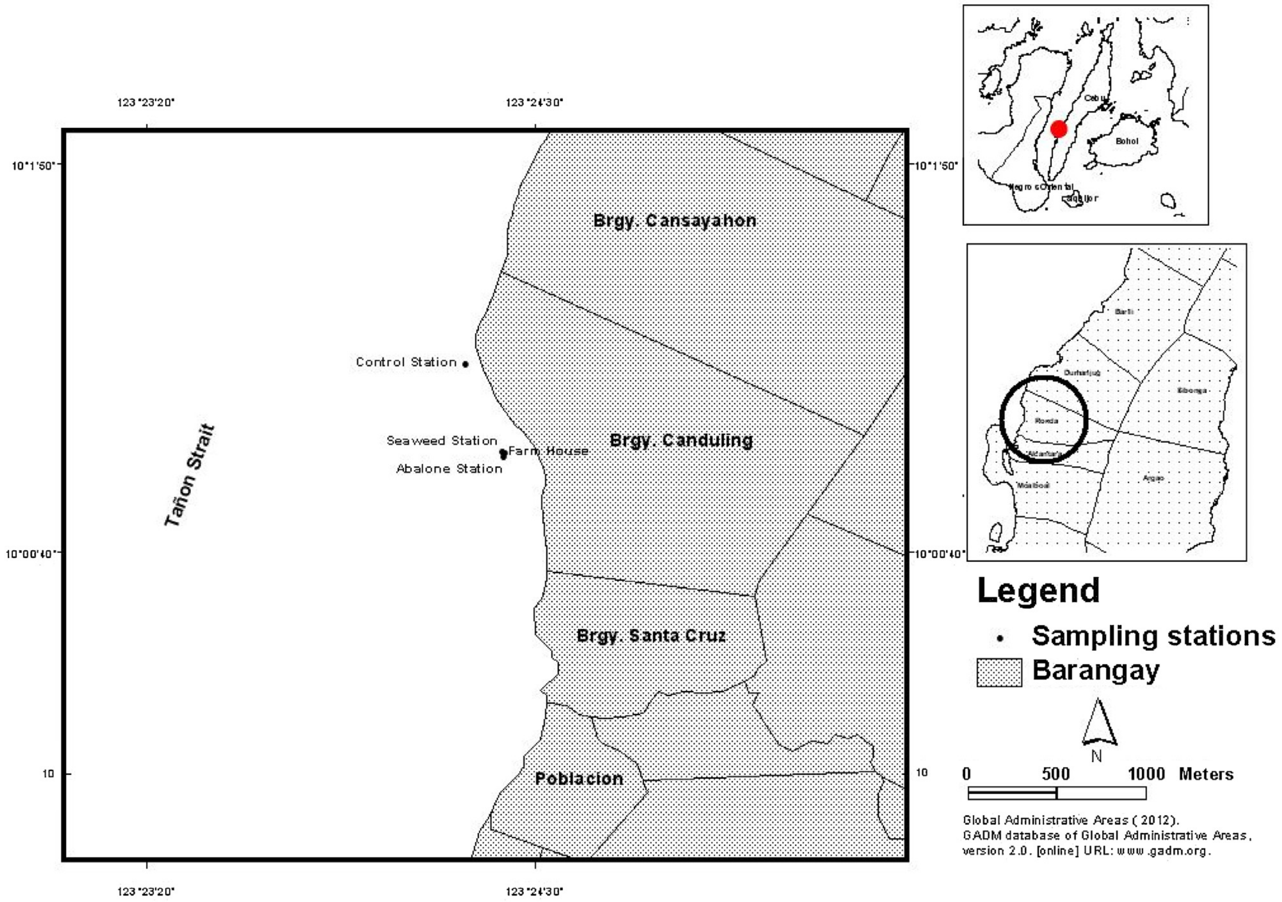
where W_f, final weight in grams; W_i, initial weight in grams; t, no. of days of culture.

Meanwhile another floating platform, designated herewith as the "Seaweed Station", was positioned next, or just about 2 m, to the Abalone Station in such a way that excreted wastes from the fed animals pass through the hanged seaweeds during tidal cycle. To determine the feasibility of growing extractive species, culture trial of the green alga *C. lentillifera* (obtained from Mactan, Cebu) was made by hanging bamboo baskets (0.5 m diameter × 0.3 m height) containing up to thirty (30) 3-g fragments of the alga. Five baskets containing the *Caulerpa* were vertically hanged in between the abalone cages at different depths of 1–5 m. Likewise a parallel culture trial was made for *G. heteroclada* and *E. denticulatum* (obtained from Mactan and Bohol Islands, respectively) by hanging 10- and 1-g fragments of each seaweed, respectively, at the Seaweed Station in a polypropylene rope (5 mm diameter) placed horizontally just below the platform. To protect the seaweeds from grazing fish a fine mesh net was placed below the seaweed lines. Growth of all seaweeds was monitored after a month, and thereafter depending on their performance.

A third station which is free from any activity was designated as a Control Station which was an area approximately 1 km away from the abalone farm and located right beside a marine sanctuary (see map in Fig. 1). The three stations (Abalone, Seaweed and Control) were sites where monitoring of physicochemical parameters were made to establish water quality profile for an initial period of one year, from February 2013 to January 2014.

2.2. Determination of physicochemical parameters

Monthly measurements of physicochemical parameters to determine ambient water quality were made using water samples collected from the three designated stations. Water samples of 0.5 L volumes were collected in duplicate in each station at the surface, middle and bottom using a 2.2 L van Dohrn$^{\text{TM}}$ sam-



Global Administrative Areas (2012). GADM database of Global Administrative Areas, version 2.0. [online] URL: www.gadm.org.

Fig. 1. Map of southwestern Cebu showing the IMTA pilot farm site located in Barangay Canduling, Municipality of Ronda, Cebu (central Philippines).

pler except at the surface which were collected manually. Water temperature and salinity were measured in situ using fluid-filled thermometer and refractometer (Atago, Japan), respectively, while pH, and total dissolved solids (TDS), which is indicative of organic waste release representing excreta and uneaten feeds from the cultured species, were measured in the laboratory using a Bante900^{TM} multi-parameter meter. Light penetration as a measure of water transparency from each site was determined using a white Secchi disk. All water samples for chemical analysis were ice-chilled and brought to the Water Laboratory of the University of San Carlos—Talamban Campus, Cebu City within less than 24 h. Nitrate, nitrite, ammonia and phosphate were analyzed according to APHA, AWWA, WPCF standard methods (Eaton et al., 2005).

2.3. Statistical analysis

All data were subjected to a one-way ANOVA analysis using Microsoft® Excel ver 2010 to determine any significant difference among stations and among depth levels, while values of each parameter averaged over the year were compared between stations and depths using Pearson correlation coefficient.

3. Results

3.1. Abalone cage culture

From an initial average size of 17 ± 1.3 mm SL × 9.8 ± 0.8 mm SW (mean, SD) in February, at a stocking density of 1000 individuals per cage, donkey's ear abalone increased in size to 24.1 ± 2.2 SL × 13.4 ± 1.4 mm SW (mean, SD) after a period of three months (Fig. 2A), with more than 90% survival rate being monitored based on initial stock of 5000 hatchery-bred juvenile abalones. A reduction in density to 200 individuals per cage resulted in growth of 29.8 ± 2.6 SL × 13.8 ± 2.7 mm SW (mean, SD) after five months. Growth reached its peak at 53.79 ± 3.01 mm SL × 26.7 ± 2.3 mm SW (mean, SD) after 12 months, with a corresponding body weight of 37.76 ± 7.61 g (mean, SD) (Fig. 2B). In terms of growth rate, abalones fluctuated considerably in average shell length (SL) at a monthly increment of as little as 0.10 mm/day in March to its highest of 3.25 mm/day in November (Fig. 2C), after which average SL fall to 1.7 mm/day in December, then to 1.34 mm/day in January. Survival rate remained high, but reduced slightly to around 90% in the latter part of 2013 when a milkfish farm nearby began operation, affecting the abalones' survival rate due possibly to increased bacterial activity from fish wastes and uneaten feeds.

In terms of body weight, the abalones grew at an average rate of 0.11 g/day but could reach as high as 0.36 g/day (Fig. 2D). However negative growth rate of −0.17 g/day was observed after the 10th month (November) which could be due to reproductive spawning of the animals as gonads were already noticeable in their mature stage.

Abalones in cages fed well with *G. heteroclada* that was either grown in the farm or imported from the Mactan ponds at a consumption rate per cage (with 6 individuals) of about 100 g per 2–3 days.

3.2. Seaweed culture trials

C. lentillifera which was used as our initial species to serve as biofilter managed to grow slightly inside bamboo baskets as shown by its rhizomes expanding outside the bamboo baskets but only for a few weeks (April–May) (Fig. 3). The seaweed began to disinte-

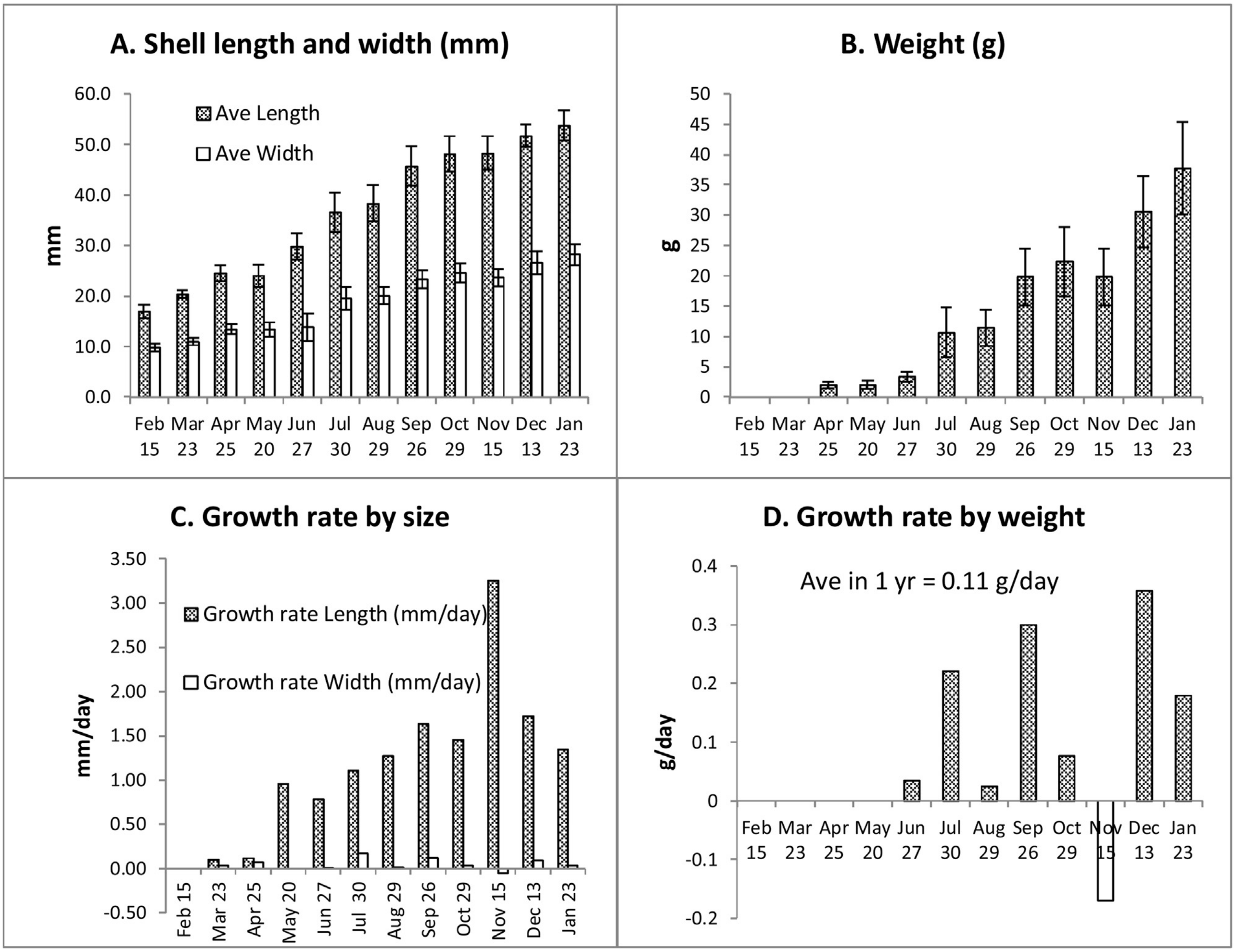


Fig. 2. Average size (shell length and width, A), weight (B), growth rate based on size (C) and weight (D) of donkey's ear abalone cultured in open sea at the Presito Mariculture farm from February 2013 to January 2014. Vertical lines in A and B are standard deviation ($n = 30$).

grate under stormy waters or strong monsoonal waves after the third week. A second attempt to culture the seaweed in late April by hanging new batch of materials, again, failed as *C. lentillifera* was too delicate to resist the impact of strong water movement during stormy weather. A change to *E. denticulatum* using the same bamboo baskets showed signs of growth, growing at a rate of 4% per day during the month of May. However, this proved to be unsustainable as subsequent *Eucheuma* cultivars gradually disappeared from the baskets due to fish grazing and fragmentation by strong waves of the southwest monsoon in June to July. The more fragile *Gracilaria*, maintained as abalone feed and at the same time serving as biofilter also did not grow fast as expected as compared to

Fig. 3. Trial culture of *Caulerpa lentillifera* in bamboo baskets (L) hanged vertically side by side with caged abalones in the open sea. Signs of growth can be seen with expansion of rhizomes after one month culture (R), but the fragile nature of its thalli did not last long due to the impact of water movement.

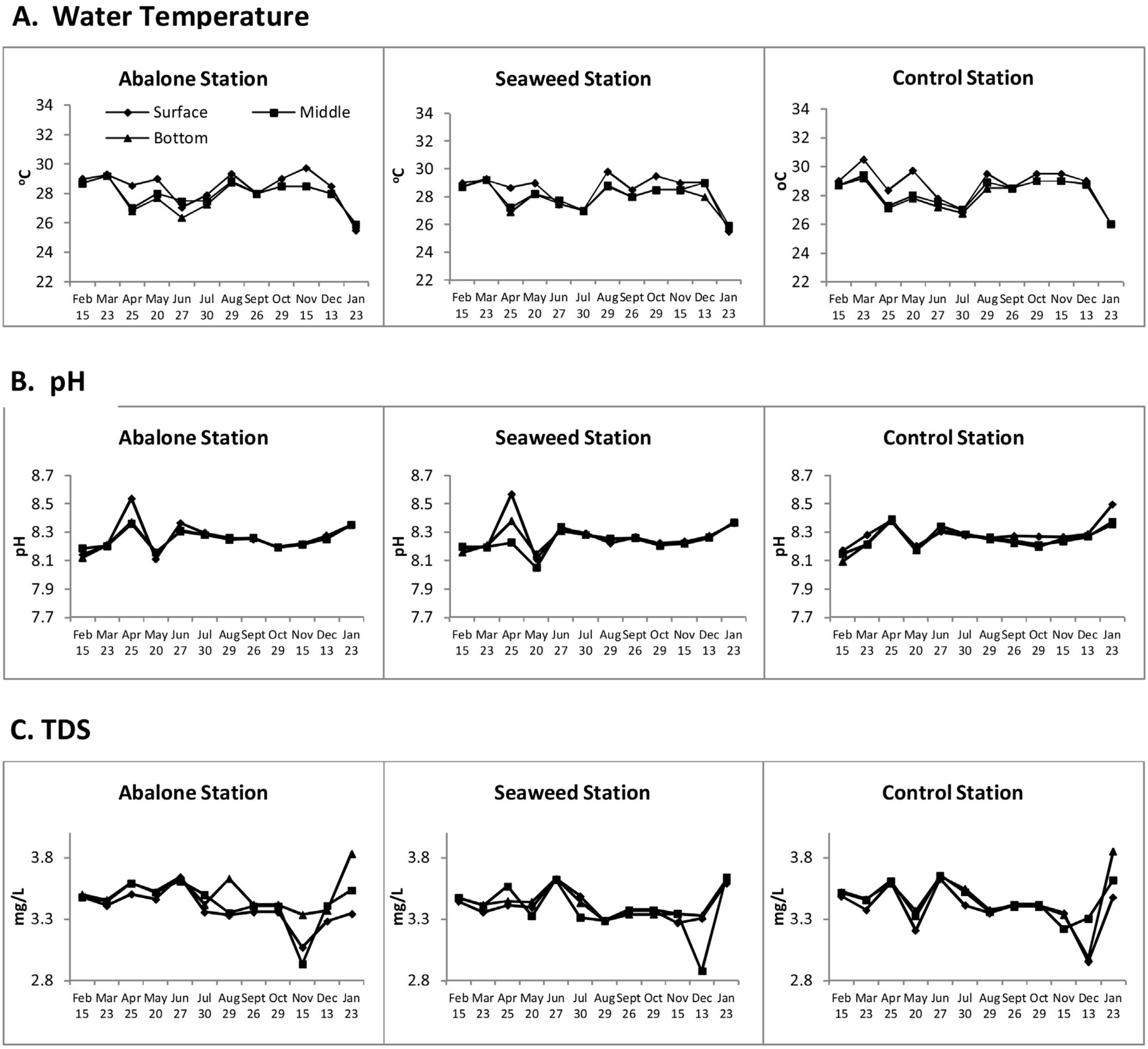


Fig. 4. Water temperature (A), pH (B), and total dissolved solids (C) measured in situ at three different depths (surface, middle, bottom) in the three sampling stations (Abalone, Seaweed and Control) from February 2013 to January 2014. Legends in (A) apply to all graph panels.

when they were normally cultured in ponds in Mactan. Using nylon ropes to hang, in horizontal arrangement, fragments of *Gracilaria* and supported by fine mesh nets placed under them, resulted to the improvement of its culture after grazing mainly by siganids (rabbit fish) was minimized.

3.3. *Field measurements of physicochemical parameters*

Average values of all parameters, while showing monthly fluctuations, did not show statistical difference among the three stations and among the three depth levels based on one-way ANOVA ($p > 0.05$) (Fig. 4).

Water temperature ranged from around 26 to 31 °C with low values recorded from April to July and high values in August to December (Fig. 4A). Bottom waters had slightly lower values than the surface waters in all three stations. Salinity fluctuated between 34 and 35 ppt while pH generally ranged from 8.1 to 8.3 except for April in one surface reading in the Abalone and Seaweed Stations where it reached 8.5 (Fig. 4B). Values of total dissolved solids (TDS) fluctuated between 2.9 and 3.8 ppm with higher TDS content recorded in the month of June and January in all stations and lowest in November for the Abalone Station and in December in both the Seaweed and Control Stations (Fig. 4C). Light penetration, based on Secchi disk measurements showed better water transparency in the Control Station (7–13 m) than in Seaweed Station (4–12 m) and Abalone Station (3.5–11.5 m).

Averaged over the year, physicochemical parameters, except for salinity, showed no strong correlation with sampling months based on Pearson correlation coefficient (Fig. 5).

3.3.1. *Inorganic nutrients*

Nitrate, nitrite, ammonia and phosphate varied in concentrations among stations and depths.

Nitrate ranged from 0.011 to 0.367 mg N/L with both extreme low and high values recorded for surface water at the Seaweed Station in April and August, respectively (Fig. 6A) (no sampling was conducted in October when a 7.2 magnitude earthquake hit Cebu, damaging the water laboratory where our monthly samples were analyzed). In the Abalone Station surface waters had higher nitrate contents in four out of six sampling months (except in August when

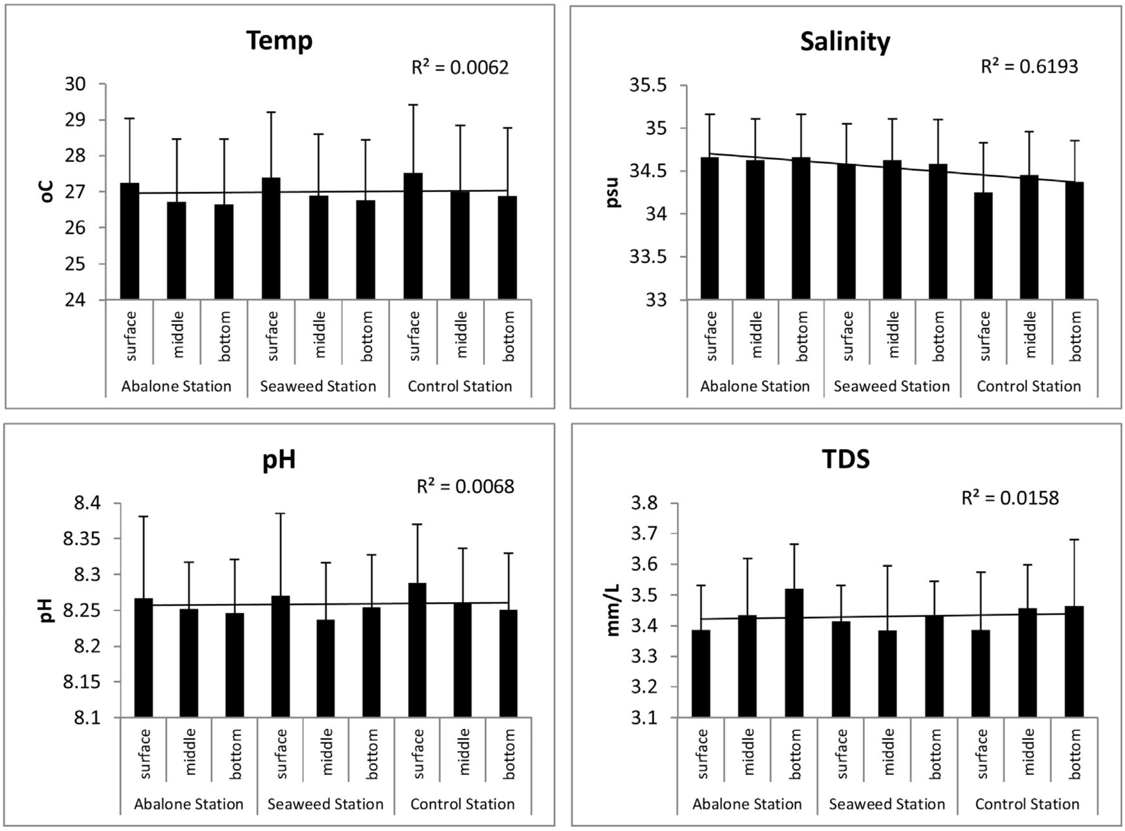


Fig. 5. Comparison of physicochemical parameters averaged over the entire study period where values did not differ significantly between stations and depths. Vertical lines are standard deviation ($n = 5$) while lines across each panel are regression lines.

nitrate values in surface and middle waters were of almost the same amount) while bottom waters had the lowest nitrate content in only one (November) out of six sampling months. In the Seaweed Station, nitrate content did not have a consistent pattern with depth levels. Nitrate in surface waters was higher than in the middle and bottom waters in only three sampling months (August, November and January), while it was higher in the middle waters than the surface and bottom waters in February and June only. The bottom water was higher in nitrate content than the surface and middle waters only in one sampling month (April). In the Control Station, nitrate values in surface waters were higher than the middle and bottom waters in three (February, June and January) out of six sampling months, whereas in the middle water, only in August that it was higher in nitrate content than the surface and bottom waters. In the bottom waters nitrate was highest only in two occasions (April and November) compared to the surface and middle waters.

Statistically, the values for nitrate between the three stations and between depths were not significantly different based on one-way ANOVA ($p > 0.05$). Averaging the concentrations over the whole study period for each station, in all depths, would indicate, however, the Seaweed Station to be relatively lower in nitrate content (0.1403 mg N/L) than the Abalone (0.1585 mg N/L) and Control Stations (0.2066 mg N/L) (Fig. 7).

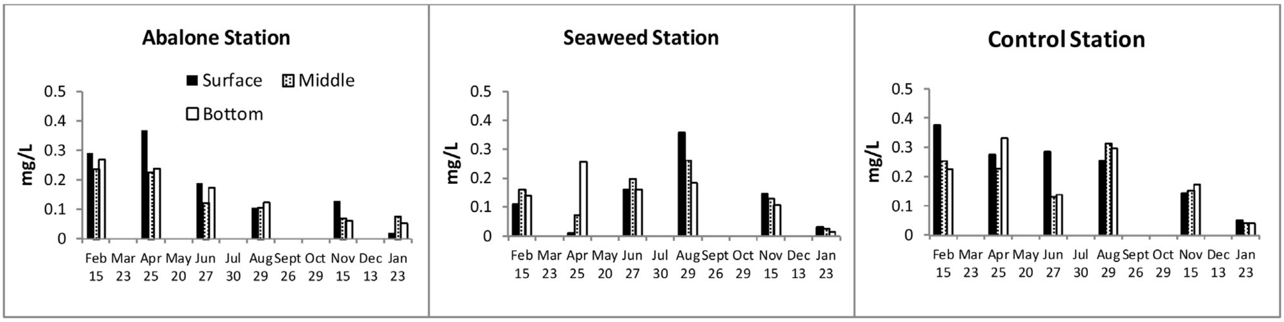
Nitrite content in water samples collected from the three stations also varied considerably in the whole sampling period, ranging from nil (no detectable amount) in April to high values of up to 0.0145 mg N/L measured in January 2014 in all three stations (Fig. 6B). Averaged over the whole year period, nitrite content was found to be slightly higher in the Seaweed Station (0.0038 mg N/L) than in the Abalone (0.0034 mg N/L) and Control (0.0031 mg N/L) Stations (Fig. 7), although not significantly different from each other ($p > 0.05$). Surface and middle waters in all Stations had the lowest average nitrite content among the three depth levels.

Ammonia likewise varied among the three stations and depth levels, with values ranging from nil to 0.105 mg N/L (Fig. 6C). Ammonia was highest in the surface waters of the Abalone Station in four of six sampling months (April, August, November, January), in bottom waters of the Seaweed Stations in four (June, August, November, January) and in the surface waters of the Control Station in three of six sampling months (April, June and August). Annual average of ammonia content of the three depth levels, showed the Abalone Station as having the highest ammonia content (0.0570 mg N/L), followed closely by the Seaweed Station (0.0544 mg N/L) and lastly by the Control Station (0.0426 mg N/L) (Fig. 7). These differences were not, however, significantly different based on one-way ANOVA ($p > 0.05$).

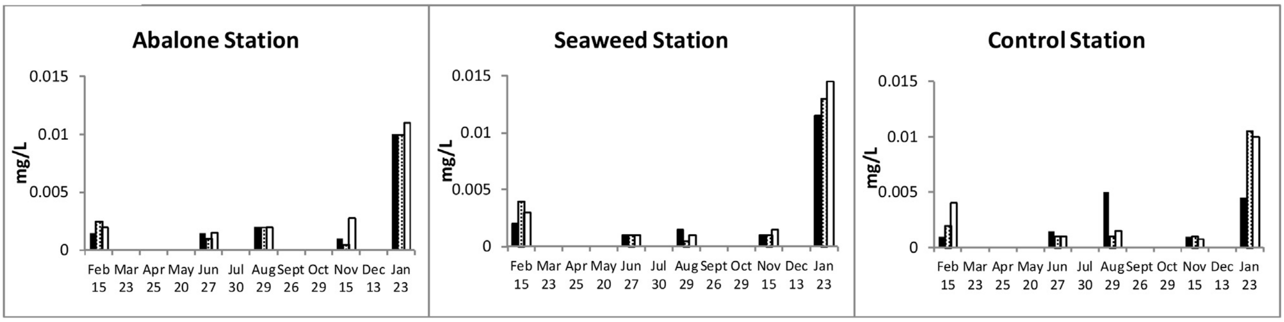
Phosphate, on the other hand, ranged from 0.001 to 0.019 mg P/L (Fig. 6D), with bottom waters having generally high phosphate content in both Abalone and Control Stations in all but one sampling month (November in Control Station), whereas phosphate concentration in bottom waters of the Seaweed Station was high only in three (April, August and January) out of six sampling months. Averaged over the year showed the Seaweed Station as having the highest phosphate content (0.0072 mg P/L), followed by the Abalone Station (0.0060 mg P/L) and by the Control Station (0.0059 mg P/L) (Fig. 7). Phosphate values between stations were not significantly different regardless of depth ($p > 0.05$).

Having no significant difference between depth levels, the values for nutrients per station were averaged over one year period. The result indicated the Seaweed Station having lower values in nitrate and ammonia when compared to the Abalone Station but the latter nutrient was higher when compared to the Control Station (Fig. 8).

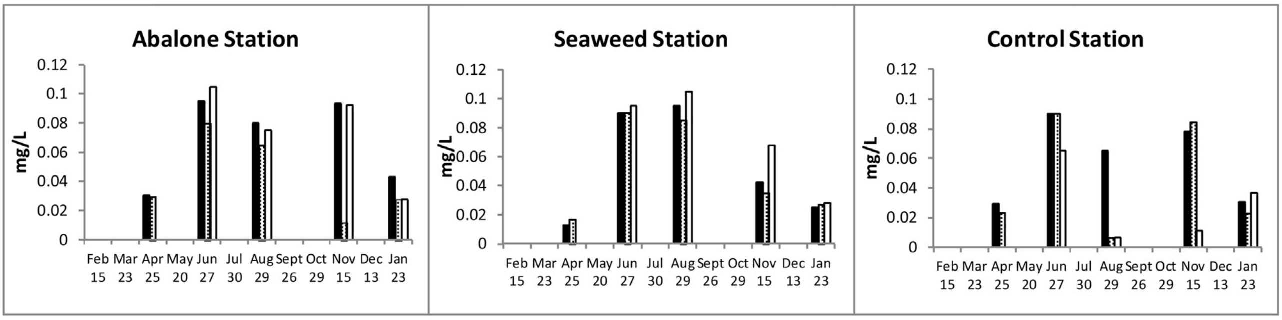
A. NO_3



B. NO_2



C. NH_3



D. PO_4

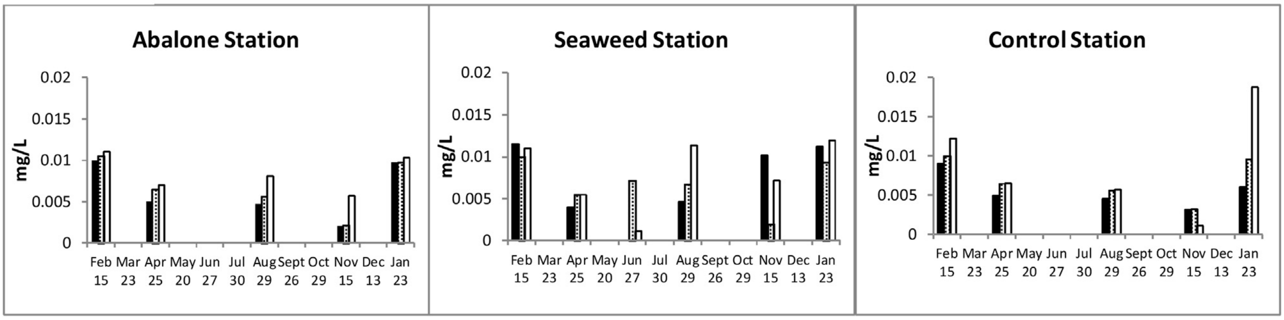


Fig. 6. Nitrate, nitrite, ammonia, and phosphate content in waters collected from three depths (surface, middle, bottom) at the three stations (abalone, seaweed and control). Values are average of two samples each. Legends in (A) apply to all graph panels.

4. Discussion

4.1. Growth of donkey'ear abalone in open sea cage culture

Donkey's ear abalone cultured in southern Cebu at an average initial size of 17 mm SL × 9.8 mm SW reached cocktail size (*ca.* 50 mm SL) in about 10 months. At six month time, the species reached an average size of 38.4 ± 3.5 mm SL and average body weight of 11.4 ± 3.0 g. Capinpin (2013) observed that *H. asinina* becomes sexually mature when shell length reaches 30–35 mm which could be the reason for the fall of growth rate in December to January.

The same species studied by Encena et al. (2013) in Guimaras Island, Iloilo obtained highest growth after six-month period (180

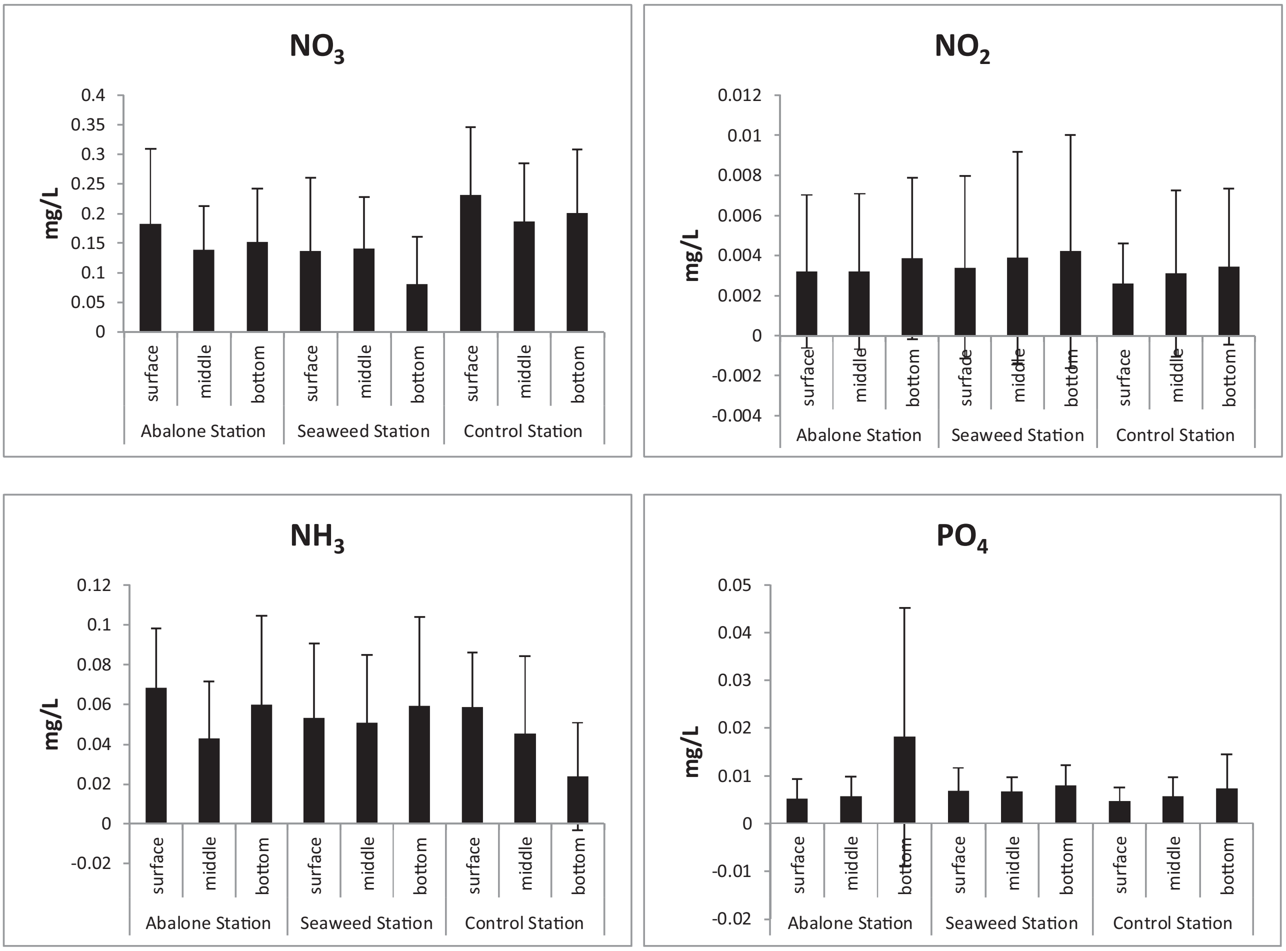


Fig. 7. Comparison between the Abalone Station, Seaweed Station and Control Station in the measurements of nitrate (NO_3), nitrite (NO_2), ammonia (NH_3) and phosphate (PO_4) averaged over the entire sampling period. Vertical lines are standard deviation ($n = 6$).

days) of 49.6 ± 0.11 mm average SL at stocking density of 50 individuals/m^2 based on an initial shell length of 26–30 mm, which they suggested as an appropriate starting size for open sea grow-outing to shorten the culture period in the field. As indicated is this study, an initial shell length of 17 mm can reach a size of close to 40 mm SL × 20 mm SW and body weight of 11 g after six months which has an average SL and BW increase rate of 1.25 mm/day and 0.11 g/day, respectively. The growth rates obtained in this study were way higher than those reported for *H. asinina* in other South-east Asian countries. For instance, in Thailand, Kruatrachue et al. (2004) reported shell length increase of 0.0967 mm/day (converted from 96.7 μm/day) and body weight increase of 0.0063 g/day (converted from 6.3 mg/day) in a tank experimental culture of *H. asinina* fed with the red alga *Acanthophora* (as Control), while in Lombok, Indonesia, Setyono (2006) reported shell length increase of 0.038 mm/day and body weight increase of 0.037 g/day for *H. asinina* fed with the red alga *Gracilaria* spp. in an offshore culture. These figures show that growth performance in donkey's ear abalone in

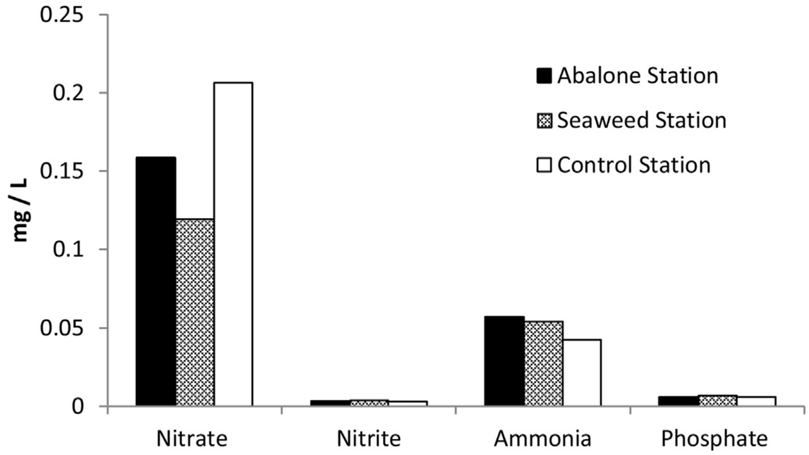


Fig. 8. One-year average values for nitrate, nitrite, ammonia and phosphate from water samples taken from the three stations (Abalone, Seaweed and Control Stations).

open-water culture depends on the size, hence age, of the abalone at the start of grow-outing as well as the stocking density especially when they reach a certain size. The open-water culture of donkey's ear abalone in southern Cebu could be shortened following these recommendations which, according to Encena et al. (2013), could lessen the risk of losses/mortalities. Thus the prospect of a successful culture of abalone in tropical waters is highly feasible.

4.2. *Potential impact of cage-cultured abalone on the ambient sea water quality*

As compiled by the Philippine Mitigating Impact from Aquaculture (PHILMINAQ) Project, the Philippines has no standards for most of the physicochemical parameters measured in this study, except for pH and PO_4 where the Department of Environment and Natural Resources (DENR, 1997) sets the limits to 6.5–8.5 for pH and 'nil' for PO_4. pH in the study area ranged from 8.1–8.3, except for one reading that reached 8.5, which could be attributed to instrument error during measurement, while PO_4 had a range of 0.001–0.019 mg P/L. Otherwise, for most measured parameters as indicators of water quality, the values obtained around the farm are well within the standards in other countries, except for ammonia where its values in the three sampling stations exceeded the water quality standards set by Australia and New Zealand. These two countries' standards for nitrate are placed at <100 mg/L, ammonia at <0.01 mg/L, nitrite at <0.1 mg/L, and phosphate at <0.05 mg/L (ANZECC 2000, as cited in PHILMINAQ, 2008), while Kenya has set the standard for TDS at 1200 mg/L (NEMA, as cited in PHILMINAQ, 2008). Although the concentrations of ammonia in the three sampling stations was not significantly different, year-round average of ammonia in these three stations showed the Abalone Station as having a slightly higher concentration of ammonia than the Seaweed and the Control Stations, indicating its source being the cultured abalones. Its concentrations which exceeded Australia and New Zealands's water quality standards could be a major concern if abalone culture is to expand commercially. In his review paper, Tomasso (1994) reported that ammonia toxicity in aquatic animals is dependent primarily on concentration and pH of the environment; high concentrations decrease survival, inhibit growth, and cause a variety of physiological dysfunctions. However, in a feeding experimental study by Basuyaux and Mathieu (1999), they showed that exposure to ammonia from low to high concentrations did not result to any mortality in the abalone *Haliotis tuberculata* and sea urchin *Paracentrotus lividus*, but it may have an influence on feeding where the authors placed the safe level for both abalone and sea urchin at 1 mg N/L done in a feeding experiment. Suspected source of ammonia around the study area could be from a nearby milkfish farm operating (since the last quarter of 2013) quite close to the Presito Mariculture farm *ca.* 200 m away.

All parameters measured within the farm did not show any significant difference in values when the Abalone and Seaweed Stations were compared to the Control Station, indicating that no negative impact has been created so far by the existence of the farm. Although the prevailing condition around the farm remained more or less the same, in which a similar observation was made by Troell et al. (2006) for abalone farming in South Africa, the certainty that this will not change over time will depend to a great extent to the volume of animals cultured in the area. Up to what extent this may be the case in southern Cebu needs to be assessed on a long term basis, i.e., a continuous monitoring of water quality will have to be done especially should the farm be increased from its current size of 0.25 hectare, to make sure that negative impact arising from the abalone culture and from external sources of ammonia and other growth-affecting factors are properly checked. This will also have to be done with a corresponding expansion in the stocking density of seaweeds which have a crucial role in mitigating excess nutrients.

4.3. *Seaweed trials using* G. heteroclada, E. denticulatum *and* C. lentillifera *as biofilters of inorganic wastes*

The co-culture of *G. heteroclada* with the donkey's ear abalone mainly to serve as source of feed with a mix of *E. denticulatum*, showed absorption capacity of the seaweeds to inorganic nutrients but only to nitrate and probably ammonia as shown by the lower average values of these nutrients in the Seaweed Station. Although field data may not always reveal the seaweeds' absorptive capacity, where various factors affect nutrient concentrations, tank or aquarium-based experiments using several species of *Gracilaria* have demonstrated otherwise, where all forms of nutrients (nitrate, nitrite, ammonia and phosphate) were removed by the seaweed (Buschmann et al., 1994; Yang et al., 2006; Troell et al., 1997; Neori et al.,1998; Mao et al., 2009; Huo et al., 2010, 2012; Abreu et al., 2011; Al-Hafedh et al., 2012). More long term observations are therefore necessary to confirm nutrient removal by *G. heteroclada* and *E. denticulatum* in the field. Maintaining a seaweed stock as "feed-on-demand", side by side the cages of donkey's ear abalone in high volume can be effective in checking the increase in nitrate and ammonia concentrations. The slightly high average value of ammonia in the Abalone Station and the waters near it (Seaweed Station) suggest the release of this nitrogenous waste by the abalones, increasing the ambient seawater with this compound in both stations. The fact that both stations had almost similar content of NH_3 can be attributed to both stations' close proximity with each other and that the seaweeds absorbed the nitrate and ammonia but not nitrite and phosphate. For *Gracilaria* to be an effective biofilter at least for nitrate and ammonia, a large amount of biomass must be maintained around the abalone cages. While this species can be maintained side by side the abalone cages enclosed in fine mesh nets to prevent grazers from entering in, this may not be the case for the green seaweed *C. lentillifera* when attempt to culture the species in baskets failed to form a biomass large enough to be maintained as nutrient filter in the open sea. Such observation contrasts with the study conducted in Australia by Paul and de Nys (2008) where *Caulerpa* grew well in more open environment with growth rates ranging from 3 to 7% per day. The present study shows that the culture of *C. lentillifera* in the open sea of southern Cebu is not effective compared to the culture of this species in earthen ponds (e.g., in Mactan Island, Cebu). In Thailand, *Caulerpa* and *Gracilaria* have been an effective filters for shrimp farm effluents (Pariyawathee et al., 2003) and for regulating water quality in recirculating water system for spotted babylon shell (Chaitanawisuti et al., 2011). Other species of seaweeds that are effective filters of ammonia has to be further explored. Species of *Ulva* which are abundant in the coastal area of Ronda, for example, can be tested in combination with *Gracilaria*.

5. Conclusion

Based on the initial findings of this study, it is possible to adopt the IMTA concept in tropical setting using local species of high market value such as the donkey's ear abalone and *Gracilaria* to make IMTA farming sustainable. The abalone could grow to cocktail size within 12 months. The combination of fast-growing seaweeds, such as *G. heteroclada* and *E. denticulatum* in the abalone culture system, is crucial for the maintenance of a balanced ecosystem as far as inorganic compounds are concerned which could accumulate over time when the farm is expanded to commercial scale. At least nitrate and ammonia, although slight only for the latter, can be absorbed by the seaweeds used.

The adoption of IMTA into tropical waters using a combination of the above species, to achieve the objective of producing protein source in the form of fed species and other marine products from the extractive species, will have a tremendous positive impact in the way aquaculture will be done in the Philippines. The choice of abalone, instead of fish, as fed aquaculture species is driven more by its low maintenance cost, high consumer demand and high market value than most fish currently in culture such as milkfish and sea bass (barramundi). However, it is important to bear in mind that, first, it is important to design an efficient IMTA system that will be adaptable to the local sea conditions where the new system will be introduced. Second, the species chosen in this system will perform its function effectively to produce commercially viable quantity. Third, the tropical IMTA is environmentally sustainable on a long term (with negligible, if not, zero environmental impact). And fourth, the new system of aquaculture will be socially acceptable to the community. Finally, ecosystems approach to aquaculture (EAA) as defined during an FAO workshop in 2007 (FAO, 2008) as "a strategy for the integration of the activity within the wider ecosystem such that it promotes sustainable development, equity, and resilience of interlinked social-ecological systems" will promote responsible aquaculture.

Acknowledgments

This study was supported by a Grant-in-aid of the Commission on Higher Education (CHED), Republic of the Philippines under its PHERNet program. The authors are also grateful to Presito Mariculture Corp. for allowing them to use its farm in Ronda, Cebu as an experimental site as well as the assistance of its staff during the study period. The Bureau of Fisheries and Aquatic Resources Region 7 (BFAR 7) is likewise thanked for providing the nursery-bred donkey's ear abalone juveniles. Finally, the Office of Research and the PHERNet Coordinating Office, University of San Carlos, for the untiring support to the PHERNet Program.

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