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Integrated Multi-Trophic Aquaculture (IMTA) of Abalone, Sea Cucumber and Seaweeds in an Intertidal Pond

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Abstract - This study presents the establishment of an integrated multi-trophic aquaculture (IMTA) system in a marine intertidal pond using high value species such as abalone, sea cucumbers, and seaweed. Cage culture of abalone (*Haliotis asinina*) as the fed species, together with red seaweed (*Gracilariopsis bailinae*) as the inorganic extractive species, and sea cucumber (*Holothuria scabra*) as the bioremediator species in an intertidal pond, did not result in any significant changes in water quality as well as sediment organic matter. The abalone were cultured at two stocking densities inside net cages installed in the intertidal pond and fed with the red seaweed (*G. bailinae*) for 75 days. No significant gain in abalone shell length and weights were observed during the culture period, but survival rates remained high throughout the culture period. Minimal growth in shell length and weight observed were due to the large sizes of abalone used in the study, which were considered already sexually mature. On the other hand, twenty-two individuals of sea cucumbers stocked beneath the abalone cages grew from an average of 95.11 mm to 172.50 mm in length and 66.23 g to 302.17 g in weight. Daily growth rate in terms of length was 1.03 mm/d and in terms of weight was 3.15 g/d, which was considered fast as compared to other studies. The high survival rates of abalone in the present study coupled with fast growth rates of sea cucumbers as well as the lack of significant changes in water quality and sediment organic matter show the potential of integrated multi-trophic aquaculture of these high-value species in an intertidal pond. The farming system is also not dependent on wild algae that needs to be harvested in large quantities for traditional culture of abalone in cages.

Key words: Integrated Multi-Trophic Aquaculture (IMTA); Abalone; Sea Cucumber; Red Algae; Intertidal Pond

INTRODUCTION

Aquaculture contributes immensely to world seafood production and food security, thus providing employment and income generation particularly to those in developing countries [1]. However, aquaculture has also been responsible for many environmental problems. For instance, fish culture requires huge amounts of artificial feed [2] wherein a lot goes to waste due to inefficient feeding practices and poor digestibility of some ingredients. In the Philippines, poor management and feeding strategies were blamed for coastal eutrophication and massive fish kills in milkfish cultured in cages in Bolinao, Pangasinan [3]. Hence, sustainable fish culture is a big challenge of the aquaculture industry especially where there is extensive use of artificial diets, which contributes to a much bigger problem in coastal ecosystems, i.e., water pollution [4].

Integrated Multi-Species Aquaculture (IMTA) is an ecosystems approach to aquaculture that has been proven to be environment-friendly mainly in temperate waters [5]. IMTA system uses cultured species that are not only commercially viable, such as salmon, but the farming system can be environmentally sustainable. It is based on the concept that the wastes consisting of uneaten food, feces, and metabolic products of one species can be used as input for growth of another species, working in a natural self-cleansing cycle [6].

Further, the integrated multi-trophic aquaculture (IMTA) system in the present study makes use of a combination of locally available species, such as the Donkey's ear abalone, *Haliotis asinina* (as the cultured species), seaweeds *Gracilariopsis bailinae* (as the inorganic extractive species or biofilter) [7], and sea cucumber *Holothuria scabra* (as the organic extractive species or bioremediator) [7, 8]. Sea cucumbers, which are detritus-feeders, have been successfully grown in shrimp ponds with good growth and survival in Vietnam [9]. Recent studies also suggest that sandfish are capable of subsisting on organic matter in shrimp ponds, and can bioremediate the sediment specifically by reduction of organic matter as well as reduced total sulfur (hydrogen sulfide and iron sulfide) in sediments [8]. The cage mariculture of abalone has also been suggested as a resource conservation strategy [10].

The objectives of this study were to co-culture high-value species (abalone, sea cucumber, seaweeds) in a marine intertidal pond under an integrated multi-trophic aquaculture (IMTA) system; monitor the growth and survival rates of abalone and sea cucumber; and monitor selected physico-chemical parameters such as ammonia, nitrite, and nitrate, phosphate, temperature, pH, and salinity as well as sediment organic matter during the culture period.

MATERIALS AND METHODS

Study Site

The study was conducted at the marine intertidal pond of the Bolinao School of Fisheries in Arnedo, Bolinao, Northern Pangasinan. The pond measured 44 m X 13.5 m for a total of 594 m^2. Water depth was 1.2 m and 0.4 m during high and low tide, respectively.

Experimental Animals

Abalone

Abalone (5 cm shell length, n=72) were collected from the wild. They were stocked in polyvinyl chloride (PVC) cages measuring 0.5 X 0.5 X 0.25 m at two stocking densities (10 and 14 abalone per cage). Inside the cages, halved PVC pipes were used as shelters.

Seaweeds

Six (6) sacks of red seaweeds (*Gracilariopsis bailinae*) were used as feed for abalone, which were gathered from brackishwater ponds in Binmaley. The seaweeds were scattered into the pond upon stocking and allowed to grow which were also periodically harvested as feed for abalone.

Sea cucumber

Sea cucumber (*Holothuria scabra*) with mean length and weight of 95 mm and 66 g, respectively were also be gathered from the wild. Sea cucumbers (n=22) were stocked directly below where the abalone cages were situated and allowed to move unrestricted inside the intertidal pond.

Culture Experiment

The abalone, sea cucumber, and seaweeds were co-cultured together in the marine intertidal pond for 75 days. Abalone were cultured in net cages and fed the red seaweed (*G. bailinae*), in order to eliminate the dependency on gathering wild seaweeds. Furthermore, the seaweed acts as biofilter by absorbing excess metabolites of the abalone, thus avoiding its build-up in the system [7]. The sea cucumbers, on the other hand, are detritus feeders and subsist on organic matter in the pond sediments. They act as bio-remediators further eliminating the build-up of organic wastes at the pond bottom.

Data Gathering

Abalone length and weight were measured every 15 d using a Vernier caliper and a kitchen weighing balance, respectively. Mean shell lengths were taken from all the stocked individuals to at least one decimal whereas mean weights were determined by taking the total biomass in each cage divided by the total number of animals. The abalone were blotted dry prior to weighing to decrease the variability in weights.

For sea cucumbers, length and weights were determined prior to stocking in the ponds and after harvest for 75 days of culture. Daily growth rates of sea cucumbers in terms of weight (DGW) and shell length (DGSL) were calculated based on formulas previously used in growth trials [11, 12]:

$$DGW\ (mg/d) = 1000GW/n$$

$$DGSL\ (\mu m/d) = 1000GSL/n$$

where GW is increase in weight (g); GSL is increase in shell length (mm); and n is days of rearing.

Monitoring of Physico-Chemical Parameters

Selected water quality parameters such as ammonia, nitrite, nitrate, as well as phosphate, which were metabolites that build up due to mariculture activities, were monitored at weekly intervals using test kits (API Marine). Other common parameters such as temperature, salinity, and pH as well as sediment organic matter were also monitored.

For sediment organic matter, the loss-on-ignition (LOI) technique was used [13]. Results were expressed as percentage weight loss on ignition (%).

Data Analysis

In the abalone growth experiment, data were analyzed using two-way analysis of variance for statistical differences in length and weights at two stocking densities and sampling days (Statistica). For sediment OM, one-way ANOVA was used to test for statistical differences per sampling period. In both cases, the data were tested for homogeneity using appropriate tests (i.e. Tukey) prior to ANOVA, and that significance was set at 95% level (=0.05).

RESULTS

Abalone Shell Length

Figure 1 shows the growth trend of abalone shell length for 75 days. There was a general trend of slight increase in shell length after 15 days, which continued until the end of the experiment. There was an increase in length from 58.28 mm to 59.95 mm in treatment 1 and 57.15 mm to 60.27 mm in treatment 2. However, two-way ANOVA showed no significant differences in shell lengths at the different time periods tested and stocking densities.

Abalone Weight

Figure 2 shows the weights obtained in growing abalone in cages for 75 days. A similar trend of slight increase in total weight was observed as the experiment progressed to 60 days. Abalone grew from 41.57 g to 50.36 g in treatment 1 and from 38.98 g to 46.57 g after 60 days of culture. The two-way ANOVA failed to show significant differences among the two treatments as well as among the different time periods tested (P>0.05)

Abalone Survival Rates

Survival rates were high ranging from 90 to 100%, with no statistical differences among treatments (P>0.05). The high survival rates of abalone cultured in cages and installed in an intertidal pond indicate the suitability of this culture technique for abalone.

Sea Cucumber Growth and Recovery Rate

A total of 12 out of 22 sea cucumbers stocked were retrieved after 75 days for a recovery rate of 54.55%. Sea cucumbers burrow into the sand during day and emerge to feed at night. Hence, it is possible that some individuals were not seen but may be still alive. After 75 days, the sea cucumbers grew from an average of 95.11 mm to 172.50 mm in length and 66.23 g to 302.17 g in weight. Daily growth rate in terms of length was 1.03 mm/d and in terms of weight was 3.15 g/d.

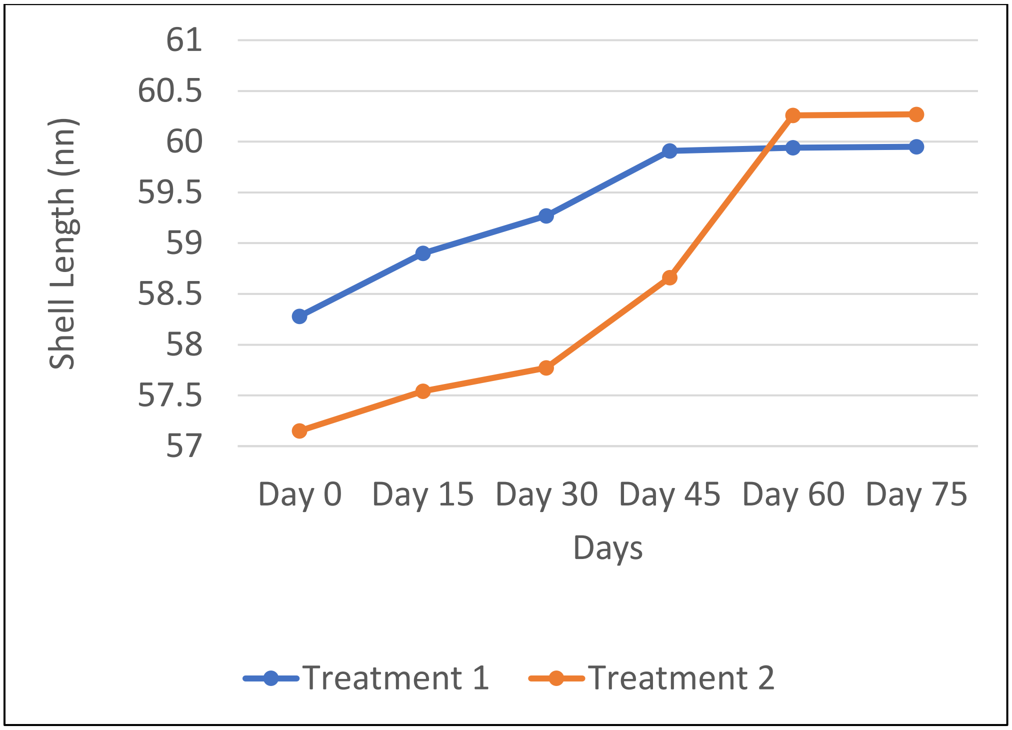

Figure 1. Mean shell length of abalone cultured at 2 densities for 75 days.

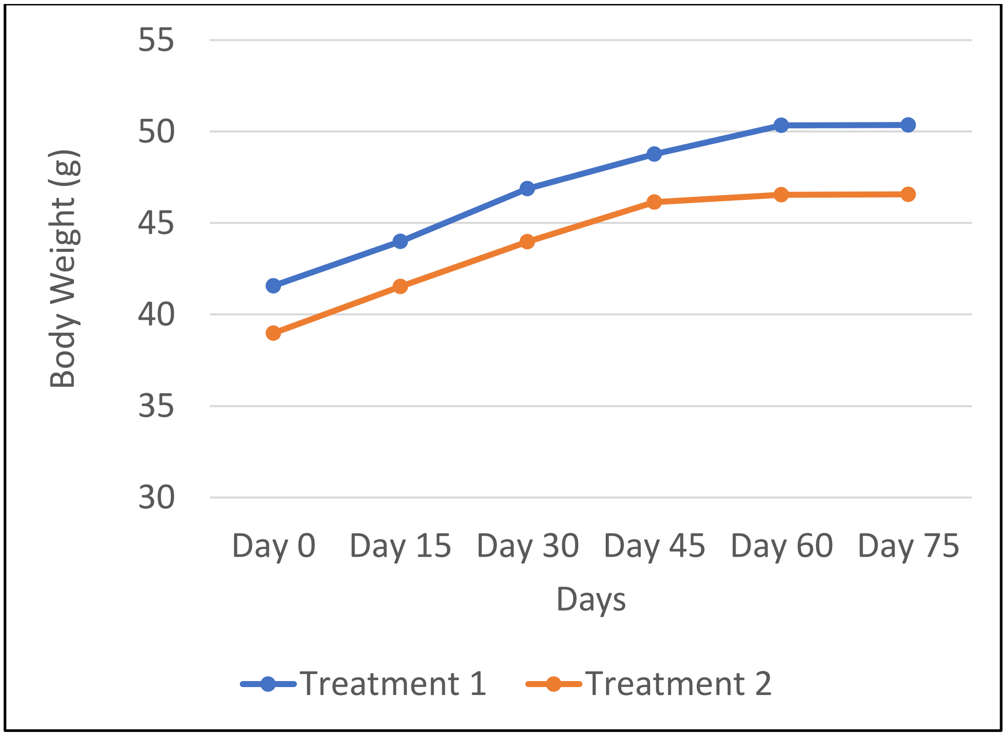

Figure 2. Mean body weight of abalone cultured at 2 densities for 75 days.

Physico-Chemical Parameters

Salinity, pH, and temperature ranged from 30 to 35 ppt, 8 to 8.2, and 28 to 30°C respectively, during the entire period of the growth experiment. Ammonia, nitrite, and nitrate remained undetectable at 0 ppm whereas phosphate level remained at 0.1 mg/L. Pond sediment OM ranged from 10.99 to 16.34%. One-way ANOVA revealed no statistical differences in sediment OM per sampling period ($P>0.05$) (Figure 3).

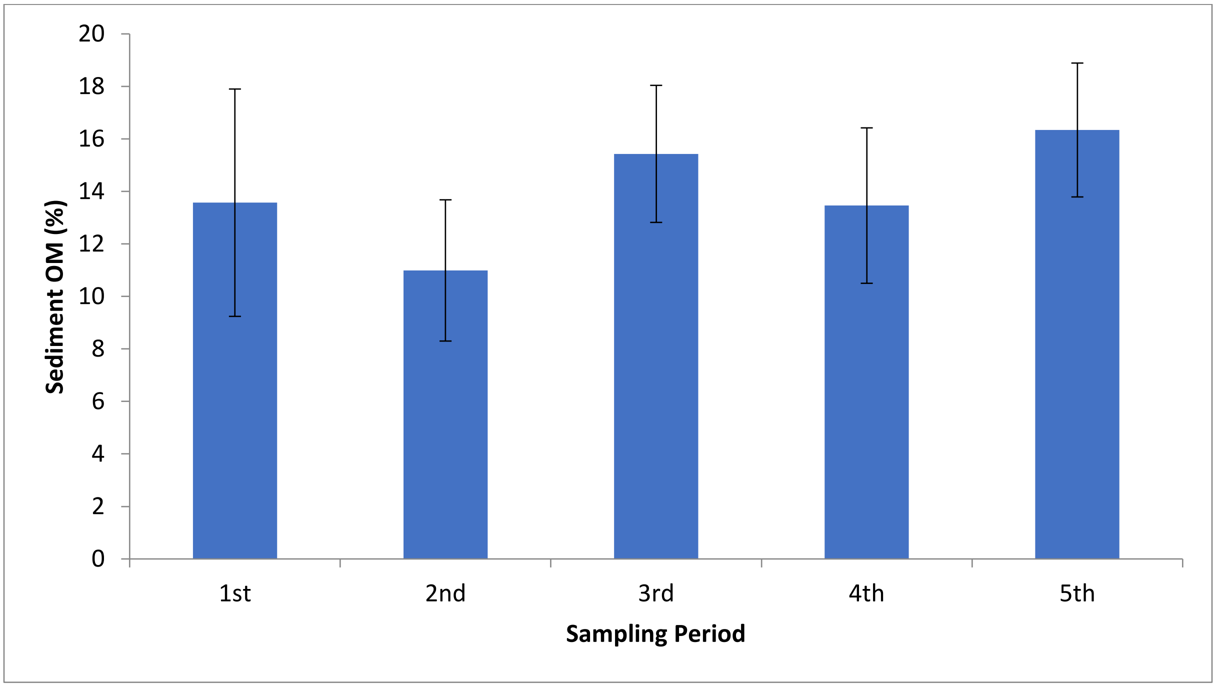

Figure 3. Sediment organic matter per sampling period (Mean±SD).

DISCUSSION

Growth and Survival of Abalone

The growth pattern observed in the present study was low as compared to previous studies using juvenile abalone [10-12] primarily because the abalone used in the study were already large and way above the size of initial maturity.

In earlier studies, the growth rates were above 100 µm/d in shell growth and above 0.20 g/d in weight for abalone stocked in sea cages with similar stocking densities. However, the survival rates (90-100%) in the present study was comparable to above 95% in the previous studies at similar stocking densities [12].

Sexual maturity for *H. asinina* is reached at a size of 35 mm for both male and female [14]. The slowing of growth rate following sexual maturity in abalone is well known and has been attributed to the channeling of energy into gonad development [11].

In future trials, it is recommended to use smaller juveniles for grow-out of abalone in cages installed in intertidal ponds to maximize the economic viability of the integrated system of culture with sea cucumbers. Nevertheless, the high survivorship of abalone in the present study shows the great potential of the integrated multi-trophic aquaculture of abalone with sea cucumbers and seaweeds in marine intertidal ponds.

Growth and Survival of Sea Cucumber

After 75 days, the sea cucumbers grew from an average of 95.11 mm to 172.50 mm in length and 66.23 g to 302.17 g in weight in the present study. The computed daily growth rate in terms of length was 1.03 mm/d and in terms of weight was 3.15 g/d. The computed daily growth rates observed in the present study were higher than that observed in tanks for 2-3 cm sea cucumber juveniles at a mean of 0.5 mm/day in length and 0.2 g/d in weight [15]. However, the present results were similar to that observed for sea cucumbers cultured in ponds in Vietnam at 1-3 g/day [9] which was considered rapid growth. Results from Vietnam suggest that a density of around 1 animal/m^2 in marine ponds (without adding feed) results to optimal growth rates and total production for a target harvest size of 300–400 g [9].

The culture of sandfish in intertidal marine ponds offer several advantages [16]. In countries like the Philippines, shrimp culture is hampered with several problems such as environmental degradation, diseases, and pollution resulting to poor production of farmed shrimp. Intensification of culture methods has also led to severe environmental pollution in ponds, resulting in anoxic sediments. As a species situated low on the food chain and subsisting only on organic matter in sediments, sea cucumbers provide better environmental effects than shrimp farming, and do not require feeding if stocked in ponds previously used for shrimp culture [16].

Results of the present study indicate encouraging results for sea cucumber. The sea cucumbers reached the target size of >300 g body weight after 75 days. However, the density used in the present study was low. Higher stocking densities may be used in the future. However, biomass should not exceed 225 g/m^2 as previous studies showed that sea cucumber growth rates decline when densities exceed this value [15].

Physico-Chemical Water Quality Parameters

Results of monitoring of water quality parameters showed no build-up of nutrients such as ammonia, nitrite, nitrate, and phosphate levels which all remained at negligible levels. Furthermore, no significant build-up of sediment organic matter was observed during the growth experiment, which remained at constant levels (10.99-16.34%), and which may also be due to low density of stocks. However, when compared with other studies done on sediment organic matter of mariculture areas, our results revealed high sediment organic matter as compared to a mean sediment OM content of 7.4% (±4.04%SD) in Calape Bay, a mariculture site in Bohol, central Philippines [13]. The high sediment OM in the present study may be attributed to slow water movement inside the intertidal pond, which was used for extensive culture of milkfish.

Earlier experiments show that organic loading in sediments can be too high for sandfish survival. In other words, in ponds there is a limit to the effectiveness of sandfish for bioremediation purposes [16]. In sea cucumber-shrimp co-culture with too much feeding of commercial shrimp starter feeds, sea cucumber survival was reduced at the highest feeding rates tested.

Largo et al. (2016) demonstrated that the co-culture of abalone and seaweeds (*Gracilaria heteroclada* and *Eucheuma denticulatum*) in the open sea did not result in any significant water quality problems in the culture area [7], and thus proving that seaweeds function as a natural filter for nutrients such as ammonia and nitrate.

The present study shows that abalone, sea cucumber, and seaweeds are compatible species to be co-cultured under the IMTA farming system. In culturing abalone, it is important to grow seaweeds alongside in order not to rely on wild stocks which may be seasonal and insufficient. Previous studies showed that the culture of abalone required large quantities of seaweed with FCRs of 18-25 for abalone fed *Gracilaria* sp. [12, 17], which makes co-culture more important. Higher stocking densities should be tried in future experiments to assess economic viability of such venture.

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