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Lessons in Sustainable Mariculture

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ABSTRACT

The Philippines has long been recognized as a center of marine biodiversity, hence, rich in marine resources. However, fisheries production has been declining in recent years. On the other hand, aquaculture now contributes about half of the total fisheries production. Notably, production from marine pens and cages (mostly milkfish) has increased dramatically in the last two decades. Mariculture areas are designed for production of marine fishes through sea cage culture, farming of seaweeds, mussels and oysters, sea ranching of abalone, aquasilviculture, and others that may be developed through continuing R&D programs. Much discussion has focused on how to achieve sustainability in aquaculture. Concerns are related to the expansion and intensification of aquaculture including its impact on the environment, outbreaks of diseases, sustainability of supply of seed, feed ingredients and feeding practices, and competition for coastal space.

Keywords:
fisheries, aquaculture, mariculture, sustainability

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INTRODUCTION

Aquaculture is one of the fastest growing food production sectors and now contributes about half of the total fisheries production. Milkfish is the top aquaculture commodity of the Philippines in terms of value, and is second to seaweeds in terms of volume of production. Although milkfish has traditionally been grown in ponds, grow-out culture has expanded to fish cages in marine waters. With intensification of aquaculture production, occurrences of mass mortalities have increased

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highlighting the need for sustainable culture practices and production systems that consider both the economic benefits and effects on the environment. Recent technological developments in mariculture and environmental monitoring protocols coupled with good governance augur well for the sustainable intensification of milkfish mariculture in the Philippines, which can be applied as Philippine aquaculture moves towards diversification to include other commercially important species.

This paper discusses the following: (a) fisheries and aquaculture production in the Philippines and (b) criteria for sustainable mariculture which include criteria for site selection and monitoring, quality indicators of water and sediment in evaluating mariculture operations, and technological indicators used in evaluating mariculture operations.

PHILIPPINE FISHERIES AND AQUACULTURE PRODUCTION

The Philippines has long been recognized as a center for marine biodiversity, hence rich in marine resources (Carpenter and Springer 2005). However, fisheries production has been declining in recent years. On the other hand, aquaculture now contributes about half of the total fisheries production (PSA 2019). Notably, production from marine pens and cages (mostly milkfish) has increased dramatically in the last 2 decades. Total fisheries production exhibited a gradual decline from 2014–2017 from 4.69 to 4.31 million metric tons (mt) and increased slightly to 4.36 million mt in 2018 (Table 1). During the same period, total capture fisheries production decreased from 2.35 to 2.05 million mt. On the other hand, production from aquaculture ranged from 2.20–2.35 million mt contributing 49.85–52.89% to total fisheries production, underlining its importance to the food production sector. Production from marine pens and cages ranged from 116.8 to 125.0 thousand mt during the same period (Table 1).

In terms of value, aquaculture has been consistently the top contributor to the Philippine economy for the period 2014–2018, with its highest contribution in 2018 at around PhP100.7 billion. Highest contribution from commercial fisheries

Table 1. Philippine fisheries production, 2014–2018 (x 1000 mt).

	Philippine fisheries production (x1000 mt)				
Item	2014	2015	2016	2017	2018
Total	**4,689.1**	**4,649.3**	**4,355.8**	**4,312.1**	**4,356.9**
Commercial	1,107.2	1,084.6	1,016.9	948.3	946.4
Municipal	1,244.3	1,216.5	1,137.9	1,126.0	1,106.1
- Marine	1,029.4	1,011.8	976.9	962.1	941.9
- Inland	214.9	204.7	166.0	163.9	164.2
Aquaculture	2,337.6	2,348.2	2,200.9	2,237.8	2,304.4
Brackishwater ponds	322.7	325.6	340.6	347.5	329.7
- Freshwater Cages/pens	150.4	155.6	154.2	158.5	160.9
- Freshwater Ponds	148.9	147.6	145.7	156.6	161.6
- Marine Cages/Pens	125.0	116.8	117.6	117.8	118.9
Others	1,590.6	1,602.6	1,442.8	1,457.4	1,533.3
- Oyster	22.2	20.3	19.5	22.9	28.7
- Mussel	18.8	15.9	18.8	19.2	26.3
- Seaweeds	1,549.5	1,566.4	1,904.5	1,415.3	1,478.3

Source: Philippine Statistics Authority (2019).

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was in 2014 at around PhP66.2 billion. Municipal fisheries from the marine environment contributed PhP71.1–84.9 billion in 2014–2018 (Table 2).

The top aquaculture production areas are MIMAROPA (17.06%), Central Luzon (9.78%), CALABARZON (7.42%) and Ilocos Region (5.40%) in Luzon; Western Visayas (7.80%) and Central Visayas (4.48%); ARMM (27.20%), Zamboanga Peninsula (9.37%) and Northern Mindanao (3.44%) (Table 3).

Seaweeds are the top aquaculture commodity with production ranging from 1.40 to 1.56 million mt between 2014–2018 (PSA 2019). Milkfish ranks second in production volume, ranging from 384.4–411.1 thousand mt during the same period (Table 4). In terms of value, however, milkfish is the top aquaculture commodity with production value ranging from PhP35,042.30–PhP40,767.8 million (Table 5). Notably, production from marine pens and cages (mostly milkfish) ranged from 105.4 to 125.0 thousand mt during the same period valued at PhP11.890.0–PhP14,043.2 million (Table 2).

Mariculture or the culture in marine pens and cages, particularly of milkfish, was introduced in the Philippines in the early 1990s as an alternative to brackishwater pond culture and attracted many investors due to the high volumes that can be harvested. Annual average production of milkfish from 1990–2007 averaged 7%, while production from brackishwater ponds during the period appeared to have leveled off, milkfish production from mariculture dramatically increased and contributed 35% to total milkfish production in 2007 (Marte 2010). To further encourage milkfish culture in marine waters, the DA-BFAR established mariculture parks all over the country with the concept of an industrial estate. Mariculture areas are designed for production of marine fishes through sea cage culture, farming of seaweeds, mussels and oysters, sea ranching of abalone, aquasilviculture and others that may be developed through continuing R&D programs. However, with intensification of milkfish mariculture, occurrences of mass fish kills attributed to high stocking density

Table 2. Value of Philippine fisheries production (2014–2018, in million pesos).

	Philippine fisheries production (in million pesos)				
Item	2014	2015	2016	2017	2018
Total	**241,943.8**	**239,702.4**	**228,934.1**	**243,901.9**	**265,348.7**
Commercial	66,189.8	64,875.3	58,866.6	59,716.3	61,044.9
Municipal	81,805.0	81,486.2	78,925.6	83,478.7	93,974.4
- Marine	71,925.1	71,718.0	71,136.6	75,346.7	84,871.8
- Inland	9,879.9	9,768.2	9,794.0	8,132.0	9,103.7
Aquaculture	93,949.0	93,340.9	91,161.9	100,706.8	100,329.3
- Brackishwater ponds	48,713.7	50,661.9	52,110.1	55,686.6	59,495.4
- Freshwater Cages/pens	10,534.9	10,882.8	10,375.4	11,838.5	12,579.7
- Freshwater Ponds	11,138.7	11,025.6	10,184.5	11,672.6	12,565.4
- Marine Cages/Pens	12,641.7	12,059.0	11,890.0	12,636.5	14,043.2
Others	10,920	8,711.6	8,581.9	8,872.8	11,745.6
- Oyster					
- Mussel					
- Seaweeds					

Source: Philippine Statistics Authority (2019).

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Table 3. Philippine fisheries production by region (% of total, 2015).

	Fisheries production by region		
Region	**Marine**	**Inland**	**Aquaculture**
Total (x1000 mt)	2,096.4	204.7	2,348.2
		% of Total	
Luzon	32.63	66.21	43.51
-NCR	5.02	-	0.08
-CAR	-	0.57	0.11
-Ilocos Region	1.59	0.81	5.40
-Cagayan Valley	1.57	5.17	0.55
-Central Luzon	1.59	6.77	9.78
-CALABARZON	4.92	49.47	7.42
-MIMAROPA	8.91	0.48	17.06
-Bicol Region	9.03	2.94	3.11
Visayas	19.0	3.45	13.53
-Western Visayas	10.15	3.00	7.80
-Central Visayas	3.84	0.09	4.48
-Eastern Visayas	5.01	0.36	1.25
Mindanao	48.37	30.34	42.96
-Zamboanga Peninsula	17.29	0.44	9.37
-Northern Mindanao	3.73	1.87	3.44
-Davao Region	1.27	0.11	1.39
-SOCCSKSARGEN	13.76	11.01	0.75
-Caraga	2.86	2.14	0.81
-ARMM	9.46	14.77	27.20

Source: Philippine Statistics Authority (2017).

Table 4. Philippine aquaculture production (2014–2018, x 1000 mt).

	Philippine aquaculture production (x1000 mt)				
Species	**2014**	**2015**	**2016**	**2017**	**2018**
Seaweeds	1,549.6	1,566.4	1,404.5	1,415.3	1,478.3
Milkfish	390.2	384.4	398.1	411.1	395.1
Tilapia	259.2	261.2	259.0	267.7	277.0
Tiger Prawn	47.8	49.5	49.1	46.1	44.8
Carp	16.8	16.9	16.8	14.6	11.3
Oyster	22.4	20.3	19.5	23.0	28.7
Mussel	18.8	16.0	18.8	19.2	26.3
Mud crab	16.2	16.2	16.9	18.1	20.8
Catfish	3.6	3.6	3.7	4.2	4.4
Others	13.1	13.7	14.4	18.5	17.7

Source: Philippine Statistics Authority (2019).

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Table 5. Value of Philippine aquaculture production (2014–2018, in million pesos).

	Philippine aquaculture production (million PhP)				
Species	**2014**	**2015**	**2016**	**2017**	**2018**
Seaweeds	10,517.7	8,315.3	6,104.7	8,301.4	10,919.7
Milkfish	35,606.8	35,143.5	35,042.3	37,623.6	40,767.8
Tilapia	19,395.4	19,390.2	18,329.4	20,466.3	21,541.7
Tiger Prawn	19,299.1	20,788.9	20,926.0	21,459.7	21,745.8
Carp	468.2	538.1.7	413.6	358.7	317.0
Oyster	179.5	180.9	203.4	259.8	310.7
Mussel	222.7	215.4	273.8	311.6	515.2
Mud crab	5,135.3	5,380.7	6,255.4	7,265.9	9,026.6
Catfish	344.2	364.7	387.9	446.9	479.2
Others	2,780.1	3,023.2	3,205.5	4,212.9	4,705.6

Source: Philippine Statistics Authority (2019).

and feeding rates, high organic load, limited water exchange and circulation leading to oxygen depletion have been recorded prompting studies on the environmental impacts of milkfish mariculture activities in an effort towards sustainability (de Jesus-Ayson 2010).

LESSONS IN SUSTAINABLE MARICULTURE IN THE PHILIPPINES

Aquaculture is considered one of the fastest growing food production sectors and contributes to food security, livelihoods and income (FAO 2018). However, there are concerns related to the expansion and intensification of aquaculture including its impact on the environment, outbreaks of diseases, sustainability of supply of feed ingredients and feeding practices, and competition for coastal space (FAO 2016). There has been much discussion on how to achieve sustainability in aquaculture. The principles of sustainability encompass the realms of the economy, society and the environment.

Site selection and monitoring

Areas for use in mariculture are chosen based on technical, social and economic viability and sustainability (Box 1; see also FAO 1989). In the Philippines, the local government units (LGUs) are mandated to enact ordinances that will define the boundaries of the mariculture area and ensure efficient and effective management and enforce regulations towards environmental preservation. The promotion of mariculture activities is envisioned as a strategic approach to introduce alternative or supplemental livelihood in coastal municipalities by encouraging fisherfolks to engage in aquaculture-related income-generating activities, as well as reduce fishing pressure in already depleted or over-fished municipal waters. Hence, mariculture activities serve as a channel to transform the fisheries sector from a highly resource-extractive livelihood to a technology-based industry. Its long-term impact is expected to usher sustainable livelihood, especially for fisherfolks while at the same time ensuring environmental protection.

In spite of its potential, mariculture is faced with several challenges to its sustainability, including reliable supply of quality seedstocks, quality feeds, outbreaks of diseases, environmental impacts (including environmental degradation, harmful algal blooms, mass fish kills), markets, economics and social issues. Many mariculture areas are not operated optimally because of a combination of these challenges. Box 2 and 3 list

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some environmental (water and sediment quality) and technological indicators that can be used in evaluating the sustainability of mariculture activities. There are several guides for monitoring of environmental parameters and impacts of mariculture activities on the mariculture sites and adjacent ecosystems (Brana et al. 2021; Aguilar-Manjarrez 2017; FAO 2009; SEAFDEC Aquaculture Department 2008; Workshop Report: Development of Better Management Practices for Marine Finfish Aquaculture in the Asia-Pacific Region 2007; BFAR-PHILMINAQ 2007; Chongprasith et al. 1999; Dang and Do 1999). Current mariculture activities in the Philippines are generally focused on medium or large scale cage culture of marine fish particularly of milkfish because of availability of seeds and feeds, and to some extent other high value fish like groupers because seeds are available from the wild (although seasonal and in low volumes) and low value fish used as feed are still abundant in some areas. However, cage culture requires considerable operational costs, especially for seeds and feeds. On the other hand, many of the sites have suitable areas for farming other commodities such as seaweeds, mud crabs, abalone and sandfish. Seaweeds farming require relatively low capital investment.

Box 1. Criteria that apply to evaluation of potential mariculture sites including the site's topography, physico-chemical characteristics, and some factors that relate to logistics and management of mariculture activities.

Topography

Presence of natural protection – Areas that are naturally protected from strong winds and big waves are preferred for this reduces the exposure of the structures to risks of possible damage from these natural physical forces. In addition, big waves will also cause some stress to the stocks. As such, marine coves are desired because wave action is generally minimal during most times of the year. The presence of land masses around the area will also be an advantage.

Suitable water depth – The depth should be such that there is enough space between the bottom of the cage and the substrate to allow sufficient water exchange around and under the cage. Sufficient space under the cage and acceptable velocity of water current will prevent the build-up of faeces, uneaten feeds and other wastes on the seafloor beneath the cages. This is very important for the sustainability of the operation especially in maintaining the overall health of the surrounding environment. Considering that the usual depth of the net cages used is between 5-7 m, areas with water depth of 10-15 m during the low tide are recommended. Areas that are too deep will require longer mooring lines and heavier anchors thus increasing the investment costs for putting up the structures.

Suitable seafloor substrate – A hard and relatively flat substrate is desired. Sand and gravel substratum is better compared to hard rocks for the latter requires heavier and more expensive mooring (anchoring blocks) for the net cages.

Suitable distance from sensitive habitats like mangroves, seagrasses and coral reefs – Mangrove areas, seagrass beds and coral reefs are natural breeding and nursery grounds for various forms of marine organisms. As such, they should not be compromised by possible negative impacts of mariculture activities. The mariculture structures should be situated preferably at least 100 meters (m) from these sensitive habitats to protect them from the potential negative effects that may result from possible pollution due to excessive feeding of the stocks in the cages.

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Physical characteristics

Acceptable water current velocity – Areas with strong water current should be avoided because strong current velocity is damaging to the structures (could warp the frames of the net cages), is stressful and could result in reduced growth rates of the stocks. Areas with strong water current will also require expensive anchoring systems for the net cages. Acceptable water current speed is preferably between 10 cm/s and 100 cm/s. In areas where current speed is less than 10 cm/s, there will be poor water exchange within and between the cages, especially at neap tide. On the other hand, prolonged exposure to current speeds of more than 100 cm/s can cause damage to the structures.

Minimal turbidity – Too much suspended solids makes the water turbid. Turbid waters tend to promote fast growth of fouling organisms that will eventually clog the nets thereby reducing water exchange through the nets. Prolonged exposure to turbid waters can also clog the gills of the fish and may cause diseases like fin-rot. On the other hand, turbid waters can also be an indication of rich plankton density, which means additional food to aquatic animals. A water transparency, measured by Secchi disc reading, of at least 1 m is desired. Sunlight penetrating the water column enhances photosynthesis of aquatic plants thereby increasing supply of oxygen in the water. Good water transparency also helps the fish to see the feeds better.

Chemical characteristics

Stable salinity – As much as possible, areas that are exposed to a wide range of salinity fluctuation should be avoided especially if the stocks being cultured have a narrow range of salinity tolerance. As such, areas that receive inflows from river waters are not desirable because this may bring excessive volumes of freshwater to the site during continuous heavy rains abruptly reducing the water salinity. In addition, river waters may also bring too much suspended solids causing siltation that is damaging to the stocks, as well as the structures.

Free from pollution – Pollution can be in the form of domestic (sewage), agricultural (pesticides/insecticides and other chemicals used in farms) and industrial wastes (toxic chemicals and wastes from factories). As such, areas that do not have factories in the vicinity, far from areas of human settlement (domestic households) and river inflows that may carry agricultural wastes are desired.

Logistical support

Proximity to various sources of production inputs like cage construction materials, feeds supply, seeds supply and other inputs is advantageous for this will reduce over-all production costs. Access to markets and other marketing support systems are also an advantage. In addition, the presence of a well-organized and active PO will be beneficial in the over-all management and operation of the mariculture activity, as well as in ensuring its long-term sustainability.

Source: Aquaculture Department, Southeast Asian Fisheries Development Center (2013a).

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Box 2. Water and Sediment Quality indicators that can be used in evaluating mariculture operations

- DO – Dissolved oxygen (DO) is considered the most critical water quality parameter. It is needed for respiration of aquatic animals. Oxygen is a sparingly soluble gas in water. Solubility of oxygen in water decreases when temperature and salinity increase. DO is increased through the action of wind and wave and photosynthesis of aquatic plants and algae. On the other hand, DO is depleted through respiration of aquatic animals and decomposition of organic materials. When DO levels become low, this may result to fish kill. DO level for marine cages should be higher than 4 ppm.
- pH – The value of pH expresses the intensity of the acidic or basic character of the water. The optimum pH range for the culture of aquatic animals is 6.5-9. Fish tends to exhibit slow growth below and above these values. Un-ionized ammonia, which is the most toxic form of ammonia to aquatic animals also increases with increasing temperature and pH.
- Transparency – This refers to the characteristic of water to allow sunlight to penetrate through the water column. Sunlight promotes photosynthesis of aquatic plants thereby increasing supply of oxygen in the water. Transparent water also helps fish to have better visibility for feeds. Too much suspended and dissolved particulates make the water turbid and reduce transparency. However, turbid water can also be an indication of rich plankton density, which means additional food to aquatic animals. A Secchi disc is used to estimate water transparency. Secchi depth of at least 1 meter is optimum for fish cage culture.
- Temperature – Water temperature directly affects the physiological processes of organisms, especially rates of fish metabolism and reproduction. The optimum temperature for the culture of tropical marine fishes is 27-31°C. An interim criterion of 2°C above the maximum ambient is recommended for ASEAN. Higher temperature decreases solubility of oxygen and enhances the toxicity of chemicals that may be present in the water. Photosynthesis of some algae is decreased at higher temperatures. Strong winds can affect temperature change by bringing up the colder water from the bottom to the surface and reduce the heating up of the surface waters.
- Ammonia-nitrogen (NH_3-N) – Ammonia-nitrogen is the principal nitrogenous waste product excreted by crustaceans and most fishes. About 0.03 kg of ammonia-nitrogen is excreted by animals per kg of high quality feed (25-40% crude protein) consumed. Ammonia, especially in its un-ionized form is toxic to aquatic animals. Other sources of ammonia especially in the coastal areas are sewage discharges and industrial pollution. As temperature and pH increase, NH_3-N also increases and this usually takes place during sunny afternoons when temperature and pH are at the highest. Its level decreases at night when carbon dioxide produced decreases the pH. The level of NH_3-N in the water should be less than 0.5 ppm.
- Nitrite (NO_2) – Nitrite is the intermediate product of the oxidation of ammonia to nitrate. Normally, it does not accumulate in the environment because it is readily converted to nitrate as it is produced, however it can accumulate to high levels when ammonia concentration is high and the rate of ammonia oxidation to nitrite is faster than the rate of nitrite oxidation to nitrate. Nitrite can be toxic to aquatic animals as it affects blood hemoglobin capacity to carry oxygen. For cage culture, nitrite level should not exceed 4 ppm.
- Phosphate (PO_4-P) – The main deleterious effect of phosphate in coastal waters is eutrophication. It is not toxic unlike heavy metals or other chemicals. However, high phosphate concentration in the aquatic environment may lead to excessive algal bloom causing depletion of oxygen. To protect

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coastal waters from eutrophication, an interim criteria of 0.045 ppm for estuarine and 0.015 ppm for coastal waters are recommended.

- Sediment organic matter (OM) – Organic matter in the sediment is composed of carbon and other nutrients such as nitrogen and phosphorus coming mostly from excreta of aquatic animals and uneaten feeds. Intensive aquaculture activity leads to heavy accumulation of organic matter, thus degrading the seabed and destroying its benthic communities. In order to oxidize and break down carbon in organic matter, the microorganisms in the sediment use oxygen causing the sediment to become anoxic (oxygen-depleted) thus reducing the amount of dissolved oxygen in the vicinity.
- Sediment/substrate color and texture – Color and texture are also indicators of the quality of the seabed. A black, muddy and clayey appearance of the substrate indicates heavy accumulation of organic matter brought about by intensive mariculture activities.
- Sediment/substrate odor – Another characteristic of high organic matter is the presence of foul odor attributed to the presence of hydrogen sulfide (H_2S), a potentially toxic gas to benthic fauna which can also potentially harm cultured species in overlying net cages. H_2S can be formed by the anaerobic breakdown of organic matter by the sulfur bacteria.
- Presence of benthos – There are communities of plants and animals that inhabit the bottom of a water body that can also be indicators of sediment quality. Aquatic plants, animals and bacterial organisms constitute the benthic community. In areas where there is high sedimentation of organic matter coming from uneaten feeds and fish excreta, no visible benthos can be observed.

Source: Aquaculture Department, Southeast Asian Fisheries Development Center (2013a).

Box 3. Technological indicators that can be used in evaluating mariculture operations

- Culture System – Monoculture refers to the culture of a single commodity or species, while polyculture refers to the culture of another species in addition to the major commodity. Integrated culture refers to the culture of several other species in addition to the major commodity. The other species utilize the excess feeds, waste products and fouling organisms present in the system. The practice of polyculture is more environment-friendly and promotes lower risk compared to monoculture.
- Source of stocks – Stocks (e.g. fry and fingerlings) for nursery and grow-out are preferably hatchery-bred and should be readily available in sufficient numbers to meet the requirements of the individual operator or mariculture area as a whole. Seed from suppliers who are relatively near the farm are preferred to minimize mortalities in fry or fingerlings associated with handling and transport stress. When seedstock supply is immediately available anytime, it is considered low-risk. A waiting period for stocks to be available of less than two months is considered medium-risk, while a waiting period of more than 2 months is considered high risk.
- Stocking density – This refers to the number of juveniles stocked per cubic meter of cage volume. Stocking density is highly variable. For example in milkfish, there is low risk when stocking density is below 25 individuals/m^3 while medium and high risk are associated with stocking densities of 25-50 and >50 individuals/m^3, respectively. Higher stocking densities will likely extend the culture period and may hasten environmental degradation.
- Culture duration – This parameter refers to the time from stocking of fingerlings in cages until they reach marketable size and are harvested. The shorter the duration of culture, the more

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advantageous it is for the fish farmer. Longer periods correspondingly increase risks.

- Survival rate – This refers to the quantity of stocks harvested relative to the number of individuals stocked. The higher the survival rate, the better it is for the operator. For milkfish culture in cages, survival rate of more than 90% is easily attainable.
- FCR – Feed conversion ratio refers to the amount of feed needed to produce fish biomass. Poor feed utilization resulting in high feed conversion ratio can be brought about by inappropriate selection of feed type (pellet type, size and formulation), quality and feeding management strategy. It is ideal to have a FCR value of less than 2, while a value of more than 3 incurs high risk of failure.
- Fallowing/cage relocation – Fallowing is an operational scheme where an aquaculture site or facility is allowed some period of rest. Breaks in aquaculture production are important since these allow the immediate aquaculture site to recover from environmental stressors. It is also an important strategy in breaking infection and re-infection cycles in case of disease incidence or outbreaks. The practice of fallowing and/or relocation of culture sites present lower risks and is therefore recommended.
- Access to technical assistance – Access to technical information and assistance in aspects of feeding management and environmental monitoring would be beneficial to ensure greater success of the mariculture activity.

Source: Aquaculture Department, Southeast Asian Fisheries Development Center (2013a).

Lessons from Panabo City Mariculture Park

Lessons on sustainable mariculture can be learned from the operations of the Panabo City Mariculture Park (PCMP), in Davao del Norte. PCMP was established in 2006 through the promulgation of a City Ordinance declaring 1,075 hectares of municipal waters in Panabo City as a Mariculture Development Zone/Park (Ayson et al., 2016). In 2011, it became the third largest among the 63 operational MPs in the Philippines with 86 private investors-locators operating a total of 322 units of cages. The success of the PCMP is attributed to the effective partnership between the government (both local and national) and the private sector.

The Comprehensive Mariculture Park City Ordinance that governs the PCMP is strictly implemented. The national government through the Bureau of Fisheries and Aquatic Resources-National Mariculture Center (BFAR-NMC), provides technical support in all aspects of the production cycle, from stocking to harvest. BFAR-NMC staff conducts regular monitoring of the water quality around the MP, the growth and health status of the stocks and compute feeding rates which are followed by the technicians/caretakers. Regulations on zoning and distances between cages are strictly enforced. Notably, the PCMP has not reported a single incident of mass fish kills, indicating that the technical guidelines for MP operations are strictly followed. The importance of technical support including regular monitoring of stocks as well as relevant environmental parameters cannot be overemphasized. Table 6 shows the comparison between selected water and sediment quality parameters in a well-managed mariculture site (PCMP) and a site where there is nobody responsible for environmental monitoring. According to the ASEAN Marine Environment Criteria, a site is considered in fair condition when water quality parameters are within the following levels: DO (> 4 ppm), NO_2 (<4 ppm), NH_3 (< 0.5 ppm), PO_4 (<0.045 ppm for estuaries; < 0.015 for coastal waters), transparency (> 30 cm). Furthermore, a site is considered good or bad when sediment quality can be characterized as follows: color (brown, good; brown to black, fair; black, bad), odor (none, good; strong rotten egg/H_2S odor, bad), texture (sandy/

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Table 6. Water and sediment quality in PCMP and another mariculture site.

Parameters	Panabo City Mariculture Park	Mariculture Park-X
Depth (m)	7.4-22.3	20.1-38.3
Dissolved Oxygen (ppm)	4.87-6.03	3.1-3.7
NH_3 (ppm)	0.024-0.072	0.075-0.093
NO_2 (ppm)	0.009-0.025	ND
PO_4 (ppm)	0.039-0.060	0.104-0.192
Organic Matter (%)	1.65-3.54	11.19-12.78
Transparency (m)	1.45-2.5	<0.5-5.75
Sediment color	Brown to black	Black
Hydrogen sulfide (H_2S) smell	None	None
Presence of benthic fauna	None	None

Source: Aquaculture Department, Southeast Asian Fisheries Development Center (2013c).

not sticky, good; clay/muddy or fine and smooth, bad), presence of benthic organisms (present, good; none, bad), and presence of seagrasses and corals in adjacent ecosystems (present, good; none, bad).

PCMP practices fallowing and/or cage relocation to allow areas under the cage used in a production run to recover from environmental stressors such as deposition of uneaten feeds and fecal matter. Data show that levels of nitrogenous wastes, phosphorus and H_2S in a mariculture area increase as biomass of the cultured stocks increase and start to decline after harvest of stocks and reach pre-stocking levels within a month (J. Lebata-Ramos, unpublished data). Fallowing is also an important strategy in breaking infection and re-infection cycles in case of disease incidence or outbreaks, although outbreaks of diseases are not commonly experienced in milkfish culture.

Integrated multitrophic aquaculture (IMTA) is a culture system that combines species of different trophic levels where waste from the fed aquaculture species (mainly finfish) are utilized by extractive aquaculture species like seaweeds and bivalves in equilibrium with the site conditions, economic balance, social interest and environmental concerns (Troell et al. 2009). IMTA systems are widely studied and practiced in China (Zhang 2016). PCMP makes an effort towards IMTA and delineates areas for culture of seaweeds, sea cucumber and mollusks within the mariculture park. However, systematic studies on the biomass of seaweeds, mollusks and benthic organisms that can sequester the amount of waste produced by a given biomass of fish produced in the park, or at least a significant portion of it, still need to be done in order to design a system that will work efficiently given the conditions in PCMP.

A reliable supply of good quality seeds is a major constraint to production, especially in an intensive culture system like marine cage farming. To address issues on supply of fingerlings, a private hatchery was established for milkfish seed production to help supply fry to the nursery operators. On the other hand, fishponds in the vicinity of the MP were utilized for fingerling production. This is a win-win arrangement for ponds operators because fingerling production in pond nurseries has a fast turn-over and is highly profitable (Aquaculture Department Southeast Asian Fisheries Development Center 2013b). On the other hand, grow-out culture in ponds is not as productive as grow-out culture in cages because stocking density is much lower.

The operation of the mariculture park provides jobs and livelihoods for many people from the community. Workers are trained and organized into

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groups by BFAR-NMC. These include caretakers, fabricators of cage frame and net cages, harvesters, fish processors, and others. Harvests are well coordinated so locators do not compete for the market. Harvests are landed in the Bagsakan Center where support facilities are provided by the government and the PCMP Producers Association. All stakeholders actively participate in dialogues related to MP operations to ensure protocols are properly followed. The strong partnership between the national government through BFAR NMC, the local government unit, the investors as well as the acceptance and support from the community for the PCMP is the hallmark of its success.

CONCLUSION

Milkfish farming has been and remains the backbone of Philippine aquaculture. Milkfish (23%) is also second to salmon (44%) among the species produced in marine aquaculture globally (FAO 2018). The technology for the culture of milkfish in marine cages (Gaitan et al. 2014) is easy to disseminate and replicate in other sites. Sustainable intensification of milkfish mariculture in the Philippines is attainable provided that environmental and technical considerations, including zoning (Aguilar-Manjarrez et al. 2017) are met.

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