Chapter 1
Aquaculture and the Environment: Towards Sustainability

Krishna R. Salin and Gabriel Arome Ataguba

Abstract The contribution of aquaculture to global fish production has increased in the last twenty years with the production level reaching 73.8 million tonnes in 2014, about 44% of total fish production. Asian and African aquaculture production accounts for a greater proportion of growth in aquaculture output. Aquaculture contributes to livelihoods as well as revenue in several countries even though the economic conditions have been inclement and environmental problems persist. Aquaculture will have to continue to grow to meet the increasing demand for fish. But growth would not be sustainable if the planning and management are not improved significantly. There is a need for local, national and international planning and management to cater for environmental, social, economic, health and animal welfare concerns. These form the core of best management practice in aquaculture. Aquaculture can impact on the environment negatively considering genetics, water quality, ecology, health and resource use while the environment affects aquaculture on three fronts: the cultured species, culture system and overall feasibility. These put together will demand some management effort in order to ensure sustainability of aquaculture depending on the application of site selection and carrying capacity assessment, aquaculture hazard and risk analysis, ecosystem-based approach to aquaculture, aquaculture governance and planning, and aquaculture certification and standards. These are discussed in this chapter.

Keywords Sustainable aquaculture · Intensification · Ecosystem approach
Risk analysis · Certification

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1.1 Aquaculture Growth

Aquaculture production in the world (excluding aquatic plants) has grown by about 62.2% from the production level of 45.4 million tonnes in 2004 to 73.8 million tonnes in 2014, and today it contributes 44% to total fish production worldwide (FAO 2014, 2016). The increase in aquaculture production is expected to be sustained via increased production from Asia and Africa with the expansion of intermediate systems and small-scale pond aquaculture, which will be aided by sound nutrition (Hasan 2001).

Aquaculture contributes to livelihoods as well as revenue in several countries even though the economic conditions have been inclement and environmental problems persist. Without considering the secondary fisheries sector and other value chain stakeholders, the FAO (2016) estimates that as at 2014, there are about 57 million people engaged in the fisheries and aquaculture sector with aquaculture accounting for about 33% of this population and Asia alone has 96% of world fish farmers. The production of fish from wild fisheries has stagnated over the last decade (Fig. 1.1) while aquaculture production and per capita supply have increased, accompanied by increase in population. However, annual per capita consumption of fish is disproportionate across the regions of the globe with a projected level of 21 kg by 2022 following increased consumption in developed nations and greater growth in Asia and Oceania but with weak development in Africa (OECD/FAO 2015).

Fast growth of aquaculture without proper planning and management has raised increasing concern over its sustainability. Aquaculture will have to continue to grow to meet the increasing demand for fish. But growth would not be sustainable if the planning and management are not improved significantly. There is a need for

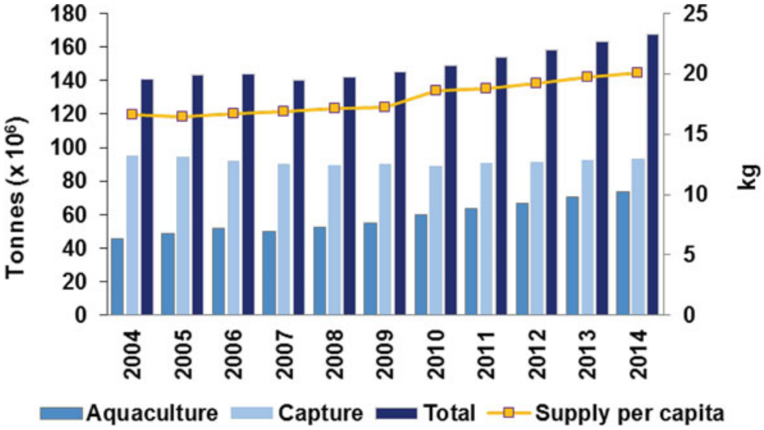


Fig. 1.1 World fish production and supply: 2004–2014. *Source* FAO (2007a, 2009, 2012, 2014, 2016)

local, national and international planning and management to cater for environmental, social, economic, health and animal welfare concerns. These form the core of best management practice as regards aquaculture.

Given the necessity to survive and maintain livelihoods among people who are employed in the aquaculture sector as well as those who are traditionally involved in fish farming both in Asia and in Sub-Saharan Africa, the exploitation of aquatic resources for aquaculture will continue. Diversity and flexibility in income generation as well as the assurance of food security are two important benefits derivable from these resources (Edwards 2002). Although aquaculture can be used as a means of eliminating unemployment and poverty, it will be totally unacceptable if the environmental impacts associated with it are sacrificed at the altar of poverty alleviation. Laxity in management and mishaps are two factors that bring about negative effects of aquaculture on the environment (Nugent 2009; Dominguez and Martín 2004).

The production of shrimps in many parts of the world have led to removal of mangrove vegetation while in some areas, inland aquaculture of marine species poses a threat to the fidelity of freshwater. In addition, the use of wild fish to feed cultured fish has become an issue of great concern. Tacon and Metian (2008) reported the empirical values for fish meal and fish oil use as against wet weight of fish gained in growth (Fish in-Fish out) for several species. Carnivorous species have the highest values in comparison with herbivorous and omnivorous fish. Filter feeding species such as oysters, clam, scallops and mussels are good nutrient absorbers and can utilize natural feed in water hence taking excessive nutrient load from the water. Integrated Multi-trophic Aquaculture uses waste products from other species as input for another species hence a combination of fed species and non-fed species in correct proportions alongside species that can synthesize food from inorganic sources such as seaweeds will result in a balanced feeding ecology bearing in mind site specificity, carrying capacity and food safety (Barrington et al. 2009).

Aquaculture makes use of land, water, wild fish and other natural resources in order to provide the right conditions for the cultured organisms to grow. Aquaculture covered about 18.8 million ha of land worldwide as at 2012 (Waite et al. 2014) while over 1.4 million ha of rice fields were used for aquaculture in China as at 2008 (FAO 2011a). Aquaculture tends to have a land utilization advantage over agriculture with the former utilizing only 0.5% of land (22.5 million ha) compared to agriculture (4.9 billion ha) in 2010 and yet producing more tonnage of fish per hectare (Boyd and McNevin 2014). Aquaculture modifies the environment, habitats, flora and fauna, scenery, proximal or in vivo water bodies as well as soil (Dosdat 2009). Continual consumption of these resources by aquaculture without a thought about sustainability will lead to depletion notwithstanding the competing claims on these resources by other sectors of productive economy. The culture system holds the key to ensuring sustainability and this according to Dalsgaard et al. (1995) can be achieved by focusing on the system and its ecology with a view to minimise the use of external inputs and to maximize the output in an integrated system. This is basically the core concept behind the ecosystem approach to aquaculture (FAO 2010) and it encompasses social dimensions (Staples and Funge-Smith 2009; Johnson 2007), governance (White and Diego-McGlone 2008) and climate change (Burrows et al. 2010).

1.1.1 Production Systems

Aquaculture production systems can be classified using several schemes. Production systems vary depending on several factors but the basic differences between them lie in water use and feeding (Emerson 1999).

1.1.1.1 Level of Intensity

The terms intensive, semi-intensive and extensive are commonly used to define culture methods. In practice, the distinction between them is often less than clear. They are, however, generally linked to the level of management input (Huntingford et al. 2012).

Aquaculture is classified according to the intensity of operations, in terms of nutrient inputs, areas used and stocking levels (Chuenpagdee et al. 2008; WRC-Report 2010). Today a lot of questions have been raised as to what constitutes each of these categories. Although Stevenson et al. (2007) were of the opinion that classifying aquaculture systems based on intensity was not easy, they maintained that the use of important variables such as stocking density, feeding rate and fertilizer application rate was necessary. The classification based on intensity as given here makes use of stocking density and feed/fertilizer application and management. However, Stevenson et al. (2007) believe that definition and measurement issues are necessary to classify production based on intensity and opined that an economic view be applied considering the fact that aquaculture production uses variable inputs (fry, feeds, fertilizer) in relation to land which is fixed.

Shang (1981), WRC-Report (2010) and Chuenpagdee et al. (2008) have given classifications based on the use of inputs as adapted above. However, as with economic measures of partial productivity, the inputs can be substituted for one another to some extent so that measuring one input cannot be totally satisfactory. With a multivariate approach to classification we can look at the particular sets of combinations of inputs that currently define production practices (Stevenson et al. 2007).

1.1.1.2 Culture Units

Earthen ponds, tanks, cages, pens and raceways are common culture units used to culture aquatic organisms (Photo 1.1). These units have to be constructed on land or in water and do carry with them an environmental impact. Cages and pens take

Photo 1.1 Intensive shrimp culture ponds are lined with HDPE liners, and well aerated with intensive feeding and regular water quality monitoring. High survival and good growth are obtained under this system. Effluents are regularly discharged from the pond by pumping from a central pit throughout the crop

advantage of the natural water resources available to produce fish without recourse to land. This is ideal for marine coastal areas and inland water bodies where current is low [<1.0 m s^{-1} Chen et al. (2008)].

1.1.1.3 Species Combination

The culture of single species (monoculture), two or more species (polyculture) and more recently a species integrated combination (Integrated Multi-Trophic Aquaculture; IMTA) are three examples of species combination as an aquaculture system. One of the fundamental concepts of IMTA is that animals and plants in the system must provide a benefit to the system and/or have significant economic value (Butterworth 2010). In this system, the by-products from one species are used as inputs (fertilizers, food and energy) for another such that fed aquaculture species (e.g. finfish/shrimp) are combined, in the appropriate proportions, with organic extractive aquaculture species (e.g. suspension feeders/deposit feeders/herbivorous fish) and inorganic extractive aquaculture species (e.g. seaweeds). This enables a balanced ecosystem management approach aimed at environmental sustainability through bio-mitigation, economic stability through product diversification and risk reduction, and social acceptability through better management practices (Barrington et al. 2009).

1.2 Threats from Aquaculture to the Environment

Aquaculture relies on water as a medium for holding the organisms under culture hence their survival depends largely on the quality of water as determined by parameters like dissolved oxygen, CO_2, carbonates, pH, NH_3, NO_2^- and NO_3^- among others. Water quality is impacted by aquaculture activities considering the use of feed, the release of waste by cultured organisms and the difficulty in separating waste from the water, which in turn has an effect on the organisms under culture. Culture systems vary and with each system, there is a unique environmental effect as a result of waste generated and management techniques. Dosdat (2009) classified waste of food origin to include: faeces, indigestible materials, un-ingested feed and ingested but undigested feed. Eutrophication is a form of organic pollution that results from the discharge of materials such as dissolved nutrients, un-ingested feed, faecal matter and deceased fish into water bodies either holding aquaculture cages or receiving aquaculture effluent. Aquaculture effluent (Photo 1.2) typically contains dissolved and suspended solids and nutrients including nitrogen and phosphorus that play a major role in eutrophication. Intensive culture systems with high stocking densities face problems resulting from bad water quality that can stress the cultured species predisposing them to disease. To counter the problems of

Photo 1.2 Effluent pumped from an intensive shrimp pond. This impacts receiving waters with increased turbidity as clearly seen here, unless directed to a water recirculating system

Table 1.1 Typical nutrient load from production of selected aquaculture species in ponds and tanks (kg/tonne of product)

Species	TSS	Total N	Total P	BOD_5	Carbon	References
Shrimp	476	15.9	1.46	63.3	730	Prapaiwong and Boyd (2012)
Trout	289–839	47–87	4.8–18.7	>944	101–565	Axler et al. (1997), Tekinay et al. (2009)
Salmon	191–606	20.3–39.3	9.1–10	410	226	Strain and Hargrave (2005), Hennessy et al. (1996)
Tilapia	382	44.95	14.26	10.4	145.6	Lin et al. (1997), Tabthipwon (2008), Neto and Ostrensky (2015)
Pangasius	2050	46–46.8	14.4–26.6	740	305.5	Anh et al. (2010), De Silva et al. (2010), Phanna (2011)
Channel catfish	353	83.6	12.7	25.6	713.5	Boyd et al. (2000)

bad water quality and disease, there is heavy reliance on chemicals and medication in the form of antibiotics (Ozbay et al. 2014).

The levels of effluent from various species under culture are presented in Table 1.1. These values were either quoted as given by the authors or derived from data presented. In cases where values were not expressed directly in kg/tonne, derivations were made based on harvest weight, concentration of variables (mg/L), volume of water and other factors relevant to the estimation. These values give a fairly good idea of the waste loading from various aquaculture species under cultivation.

Advances in aquaculture technology has created room for culture of hitherto uncultured species of high value in developed countries with increased demand for feed (Photo 1.3) and other inputs that impact on the environment. Intensification of aquaculture for production of export value species has been a point of focus by environmentalists in their quest for environment friendly food production,

Photo 1.3 Types of aqua-feeds: pellets for tilapia grow-out (left) and broodstock feed for groupers (right)

Table 1.2 Environmental threats from aquaculture (Emerson 1999; Kura et al. 2004; USAID 2013; Ozbay et al. 2014; Boyd and McNevin 2014)

Threat	Hazard	Risk
Genetic	Escapes	Fitness issues
	Exotics/GMO's	Genetic contamination; loss of biodiversity
	Wild broodstock	Introgression
	Stock enhancement	Extinction
Water quality	Effluent	Eutrophication; pollution
	Sediments	Habitat loss
Ecology	Land modification	Habitat alteration
	Salinization	Loss of freshwater
	GHG emission	Pollution; climate change
Health	Antibiotics	Resistance
	Chemicals	Pollution; bioaccumulation; toxicity
	Escapes	Disease
Resource use/Inputs	Fishmeal	Depletion of wild fish population
	Wild seedstock	
	Water extraction	Water shortage

GMO genetically modified organism, *GHG* green house gas

considering species like trout and salmon in Europe and the United States, and recently tilapia and pangasius in Asia (Bosma et al. 2011; Boyd and McNevin 2014).

Several attempts have been made to categorize the various threats from aquaculture to the environment. A concise classification of the threats posed by aquaculture to the environment is given in Table 1.2. Aquaculture facilities impact directly on water bodies that feed them water since the same water bodies receive effluents discharged. The effects are more pronounced in lakes and stagnant canals that serve as water sources, through changes in microbial communities as well as toxicity of discharged chemicals (Ozbay et al. 2014). While fertilizers can cause nutrient levels to rise leading to eutrophication, lime does not present any environmental threat; but the use of human waste is a potential hazard that raise food safety concerns (Boyd and Massaut 1999).

1.2.1 Genetic

Anthropogenic interventions in aquatic ecosystems do not stop at extraction alone since there are efforts to restore depleted feral fish populations through enhancement activities that come under three broad categories: Sea ranching, stock enhancement and of fish introduced in therestocking (Bell et al. 2006). Fisheries enhancement through hatchery produced fish has long been practiced as a means of recovery for depleted wild fish populations as well as conservation (Wada 1998; Antunes et al. 1999). Inland fisheries enhancements have utilized introductions and stocking as a means to improve fish populations (Cowx et al. 2012). The use of stock enhancement techniques in marine fisheries has come with mixed economic results ranging from failure: shrimp in Western Australia (Loneragan et al. 2006), Japan (Hamasaki and Kitada 2006), and China (Wang et al. 2006) to successes: scallop in Japan (Uki 2006) and New Zealand (Lorenzen 2008), and chum salmon in Japan (Hilborn 1998; Kitada 2014). In terms of biological impacts, stocking has been reported to have led to high mortality of feral salmon as a result of cannibalism by stocked fish (Pearsons and Fritts 1999).

Risks from introduction of exotic fish for culture depends on the probability of their establishment and that of occurrence of an adverse effect following their establishment (Miller et al. 2004). This is particularly true considering the fact that out of eleven species of fish introduced in the Hawaiian islands, only three species became established although factors such as number, duration before maturity, larval survival and water depth are key predictors (Johnston and Purkis 2016). Risk assessment of non-native species for introduction in Brazil revealed that all non-natives were unsuitable for use considering the high level of ecological risk associated with them (Britton and Orsi 2012).

Genetic manipulations and escapes of farmed species have the potential to initiate and establish losses in genetic diversity. Intra-specific diversity can be lost or degraded through genetic drift in bottlenecked populations, extinction and hybridization. Genetically modified organisms (GMO's) pose unknown and undetermined threats to natural populations. The use of risk assessment in determining effects of GMO's to natural populations is strongly advocated (Muir 2004).

Escapes of fish from aquaculture facilities can lead to fitness issues as observed in several studies (McGinnity et al. 2003; Weir and Grant 2005; Weir et al. 2005). Although Weir et al. (2005) reported differences between wild and farmed male salmon in terms of mate preference and reproductive success, Lehnert et al. (2012) reported that sperm fitness was greater in farmed than wild male chinook salmon. Susceptibility to predation of salmon is not related to size with equal probability to predation being reported (Solberg et al. 2015). On the whole, mathematical modelling suggests a strong non-linear relationship between impacts of escape, population of escapes and their reproductive viability while less adapted populations escaping at steady and low-levels can lead to proliferation of mal-adaptation in wild populations (Baskett et al. 2013). Poor broodstock management and breeding has led to production of highly inbred lines of giant river prawn, *Macrobrachium rosenbergii* in India (Nair and Salin 2012).

1.2.2 Water Quality

Aquaculture effluent contains both organic and inorganic materials that tend to increase the load in the environment where the effluent is released. In receiving waters, changes have been observed in the community structure of organisms with an increase in the number of organisms that depend on deposits from mussel aquaculture cages in South Africa (Stenton-Dozey et al. 1999). However, mussel cage aquaculture is reported not to affect the holding water body negatively in the Western Adriatic sea (Fabi et al. 2009) and South-eastern Brazil (da Costa and Nalesso 2006). Poor water quality is often dependent on other anthropogenic factors apart from aquaculture (Boyd and McNevin 2014). This is particularly true for mollusc aquaculture that is often used as a remediation for effluents than as a contributor. According to Rawson et al. (2002), bivalves and molluscs can effectively remove nutrients in moderately enriched waters as against heavily enriched waters. Effluent from ponds have less impact on receiving waters than domestic waste water, except for high total suspended solid concentration (Boyd and McNevin 2014). However, large scale aquaculture as well as clustered small holder farms tend to pose a problem to future aquaculture development within the same area they are located, and by extension world aquaculture due to eutrophication (Rawson et al. 2002). Nutrient enrichment has led to unsustainable economics of shrimp production in Krung Krabaen Bay and Welu wetlands in Thailand (Ataguba et al. 2014). In India, direct effluent discharge from *Macrobrachium* farms was responsible for eutrophication in the receiving waters of the densely populated state of Kerala compared to Andhra Pradesh (New et al. 2008).

Aquaculture can be carried out using either fed or non-fed species with the latter having a goal to reduce resource use in the form of feed while also ensuring environmental integrity (Photo 1.4). Feed use however tends to cause high levels of

Photo 1.4 Shrimp grown together with mussel in a pond in Thailand for environmental integrity

nutrient loading in receiving waters considering uneaten feed, faeces, and other biological waste produced through metabolism (Davis 2015). Depending on the prevailing circumstances in receiving waters as well as released concentration, discharge of nutrients as a result of bad feeding strategy as well as use of poor quality feed can either be assimilated or accumulated leading to pollution (White 2013). Clustering of farms tends to create a huge pool of feed that produce large quantities of waste (Craig 2002). The extent of pollution from nutrients of feed origin depends on the hydrodynamics of the water body, windswept, rate of loading, stocking density, FCR and spacing of farm units (White 2013). Modelling has been proposed as a means to create a balance between fed and no-fed aquaculture as well as human activities (Rawson et al. 2002).

1.2.3 Ecology

Shrimp farming has negatively impacted coastal ecosystems via mangrove loss and associated biodiversity changes (WorldBank 1998; Rajitha et al. 2010; Paez-Osuna 2001). Mangrove forests mitigate erosion, maintain coastal water quality, provide breeding grounds for aquatic organisms, and provide vital ecosystem services for people along the coasts (Valiela 2006; FAO 2007b). World mangrove forest cover has reduced from about 188,000 km^2 in 1980 to 152,300 km^2 in 2005 (Fig. 1.2).

Mangroves link terrestrial and marine ecosystems in about 124 countries with tropical or sub-tropical climate, are halophilic, evergreen, and thrive on sheltered coastlines, estuaries and deltas (FAO 2007b). Mangrove deforestation has occurred in all five continents of the world between 1980 and 2005 with a total of 36,000 km^2 lost within 25 years (Fig. 1.3).

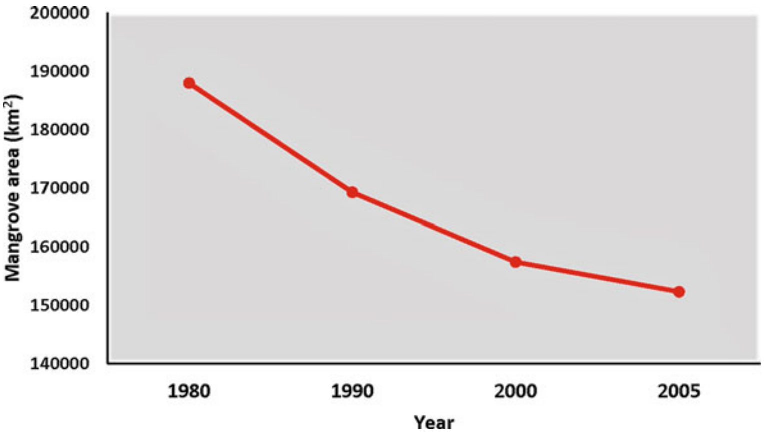


Fig. 1.2 Change in world mangrove area cover due to aquaculture and other human activities, 1980–2005. *Source* Spalding et al. (2010)

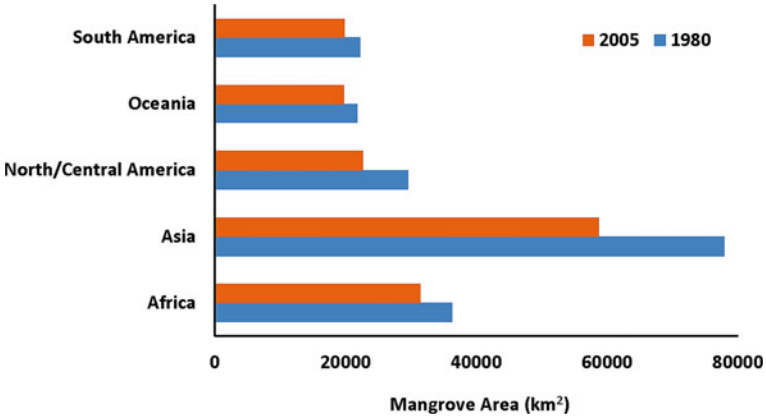
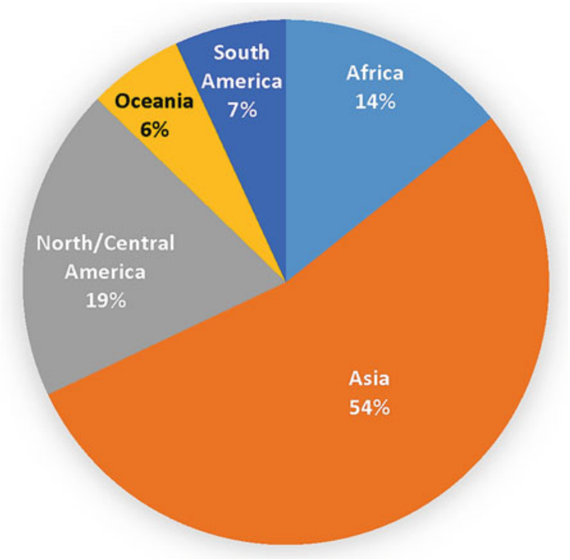


Fig. 1.3 Regional mangrove cover change, 1980–2005. *Source* FAO (2007b), Spalding et al. (2010)

Fig. 1.4 Regional percentage of world mangrove area lost, 1980–2005. *Source* FAO (2007b)



Drivers of change of mangrove area cover are mainly anthropogenic and include land use for agriculture, aquaculture, tourism, recreation, and development of infrastructure (FAO 2007b; Giri et al. 2008). Although Asia has the lowest mangrove area cover to land area ratio, it has the largest area of mangrove cover in the world, but the loss is also high. About 54% of total world mangrove forest area lost between 1980 and 2005 was from Asia (Fig. 1.4) and aquaculture contributed to this loss by 12% (Giri et al. 2008).

Construction of shrimp ponds entails mangrove destruction and from experience, excessive numbers of farms clustered along the shorelines lead to reduced productivity with attendant disease conditions and collapse of the ventures. A shift in livelihoods from aquaculture to fishing becomes impossible since breeding grounds and nursery areas have been destroyed hence recruitment altered and population of feral aquatic organisms must have migrated to favourable grounds or died out totally. This underscores the need to consider livelihood options in the context of sustainable aquaculture (Emerson 1999).

Coastal aquaculture of shrimps utilizes seawater or brackish water. Introduction of saline water for inland shrimp farming would increase soil and water salinities due to seawater and sediment discharge into inland water bodies (Tucker et al. 2008). Salinization of soil due to shrimp aquaculture has been reported in Bangladesh (Chowdhury et al. 2011) and Thailand (Teng 2008).

Energy use in aquaculture ponds for aeration is largely responsible for greenhouse gas emission associated with aquaculture (Pelletier and Tyedmers 2010). However, emission from aquaculture appears to be quite low (2.2%) compared to other food production sectors (Boyd and McNevin 2014) with tilapia production having an emission intensity that is quite lower than pork and beef production but comparable to broiler and Atlantic salmon (Pelletier and Tyedmers 2010). Removal of mangroves to pave way for shrimp aquaculture is detrimental to the environment since mangroves are very good storage units for carbon and their removal has the potential to contribute to climate change (Ahmed and Glaser 2016).

The persistence of organic matter in the environment depends on several factors including moisture, temperature and related microbial/chemical activity (Estrada and Soares 2017). There is a direct relationship between plant biomass and soil organic carbon with areas that have heavy vegetation being storage depots for emitted carbon (Alavaisha and Mangora 2016).

Carbon stocks vary across the globe with increasing concentration at the equator and it currently stands at a global average of 78 tonnes C ha^{-1} year^{-1} while sequestration is at a rate of 2.9 tonnes C ha^{-1} year^{-1} (Estrada and Soares 2017). Research has shown that above the ground plant biomass hold more carbon with reports of mangroves holding between 414 and 684 Mg C ha^{-1} in two areas of Tanzania (Alavaisha and Mangora 2016), 147 Mg C ha^{-1} in the Eastern coast of India (Sahu et al. 2016) and 853–1311 Mg C ha^{-1} in mangrove wetlands around Papua and East Indonesia (Taberima et al. 2014). The impact of mangrove removal for aquaculture as well as other anthropogenic needs on the ability of mangroves to sequester carbon from the environment is not readily quantifiable considering lack of information covering the extent of carbon sequestration by mangroves in wetlands and even below the earth surface (Donato et al. 2011).

1.2.4 Health

Water which is the medium of aquaculture is also the cradle of life since it supports numerous organisms both beneficial and harmful to human beings. The nutrient load that emanates from aquaculture gives a favourable environment to micro-organisms. Pathogenic organisms are ever present in the environment but their pathogenicity depends on the level of management and the aquaculture facility being used. Semi-closed systems present the greatest risk of pathogen transfer from farmed to wild fish (Huntington et al. 2006). Transmission of pathogens and parasites between farmed and wild fish and vice versa is however difficult to determine considering three critical points mentioned by Murray (2015), which include the presence of the pathogen in the fish at harvest, presence during processing and transmission from source to recipient. The latter can create unreliable outcome since the determination of points of outbreak and emergence of either a parasite or pathogen may not be accurate except where product traceability is complete. Sepúlveda et al. (2004), presented a report that is contrary to the wide-held thought that cultured fish can transmit pathogens and parasites to wild fish. They observed that wild fish in southern Chile that were in full interaction with cultured fish had greater parasite load than cultured salmon. Similarly, Sanil et al. (2010), reported that the intensity of protozoan (*Perkinsus olseni*) infections in wild pearl oyster (*Pinctada fucata*) was higher than cultured oysters. However, sea lice infection in farmed Atlantic salmon was found to be intermediate between two wild stocks (Glover et al. 2004).

The use of antibiotics in aquaculture is perceived to cause antibiotic resistance in unintended species in the environment. In Asia, a total of 36 antibiotics are used in aquaculture (Rico et al. 2012) and according to Anka et al. (2013), farmers use antibiotics without receiving advice and they use these at self-determined doses (Photo 1.5). In China, bacterial strains in shrimp hatcheries with known resistance to antibiotics were found to differ in resistance with pond water bacteria having a

Photo 1.5 Some of the common antibiotics used in a commercial shrimp hatchery: oxytetracycline (left), product of unknown composition (centre) and erythromycin (right)

strong influence on the resistance capacity of sediment bacteria (Zhang et al. 2011). Le et al. (2005), also reported the incidence of antibiotic resistance in bacteria from shrimp farms in Vietnam especially *Bacillus* and *Vibrio*. The diversity of antibiotic resistant genes is also greatly enhanced by aquaculture (Harnisz et al. 2015).

The use of chemicals in aquaculture is generally believed to be safe except in circumstances where management is negligent. Chemicals used in aquaculture include lime, fertilizer, therapeutants, anaesthetics, hormones, oxidants, algicides, coagulants, feed additives, antifoulants, fuels and lubricants (Boyd and McNevin 2014). Treatments for parasites in fish often rely on chemicals such as $KMnO_4$, formalin, salt, iodine, organophosphates, hydrogen peroxide, chlorine and chloride compounds, and $CuSO_4$ among others (Rico et al. 2012; Ataguba et al. 2013; Boyd and McNevin 2014). Disinfectants such as $KMnO_4$, chlorine compounds, formalin and iodine can be highly toxic to macroinvertebrates and planktonic organisms but their persistence in the environment is low (Rico et al. 2012). Treatment of sea lice in salmon involves the use of various chemicals including organophosphates, hydrogen peroxide, pyrethroid and pyrethrins, which end up being toxic to non-target organisms such as insects, crustaceans and other macroinvertebrates (Page et al. 2005).

1.2.5 Resource Use/Inputs

Despite the declining wild stock, small pelagic fish are being caught and rendered as fishmeal and fish oil to produce aquaculture feeds. Excessive use of wild fish to manufacture aquaculture feed hurts the environment since sustainability is not possible. According to FAO (2014), about 15% of the total of 891 million tonnes of fish produced between 2007 and 2012 was used for feed and other non-food uses, but this quantity was reported to be in decline. This decline can be attributed to the increased use of ingredients of plant origin as well as other animal by-products in formulated feeds for aquaculture.

Although the collection of wild mullet fry for aquaculture had not shown any visible effects in Egypt between 1983 and 2008 (Saleh 2008), in India and Bangladesh, giant tiger shrimp fry collection had led to discards of up to 160 other fry per tiger shrimp (Naylor and Burke 2005), leading to a ban on its collection due to the obvious effect this had on the recruitment of bycatch species (Siriwardena 2007). However, wild fry collection in Bangladesh had shifted to the freshwater prawn (*M. rosenbergii*) with varying percentages of bycatch for either types of gear used (Ahmed and Troell 2010).

The agriculture sector is a major consumer of water. One of the major drivers for increasing world water demand is the abstraction for agriculture, including crops, livestock and aquaculture, apart from the rising demands for domestic and industrial use. A lion's share of this freshwater demand is for irrigation in crop production. Globally, agriculture uses up about 70% of the total freshwater abstraction, while this could be as high as 90% in most developing countries (FAO 2011a). In developed countries the use of freshwater for agriculture is quite low (up to 5% of global consumption), but more water is exploited for industries and energy production (15%). Domestic and municipal consumption account for 10% of the global extraction of freshwater (WWAP 2016).

Abstraction of water for aquaculture is inevitable since water is the most important factor in aquaculture. Extensive and semi-intensive pond aquaculture have low water demand compared to intensive flow-through systems (Beveridge and Phillips 1990; Boyd and McNevin 2014). The production of between 4 and 12 kg of rainbow trout annually in flow-through systems in Ontario utilized about 526,000 l of water (Moccia and Bevan 2005). Aquaculture consumes less than 1% of the world's freshwater that is renewable and reachable (Boyd and McNevin 2014). Considering this, water use by aquaculture may have little impact at the global environmental level.

1.3 Threats from the Environment to Aquaculture

Aquaculture is dependent on the environment hence there is a cyclic relationship between them such that the environment affects aquaculture while aquaculture also impacts the environment. Basically, environmental factors as they affect aquaculture can be managed through proper site selection but environmental hazards that occur as a result of weather and climate are often deleterious to aquaculture. Furthermore, anthropogenic activities also place some form of stress on aquaculture and the aquatic organisms under culture with concomitant effects on humans who in the first place caused the upset. These are considered as challenges to aquaculture (Mazur and Curtis 2006).

The environment limits the ability to culture certain species or adopt certain aquaculture practices. This is particularly true considering the fact that culture of cold water species like trout is difficult in the tropics and culture of marine species in land locked areas is also difficult. This notwithstanding, control of the environment for aquaculture of certain species can be achieved considering their plasticity.

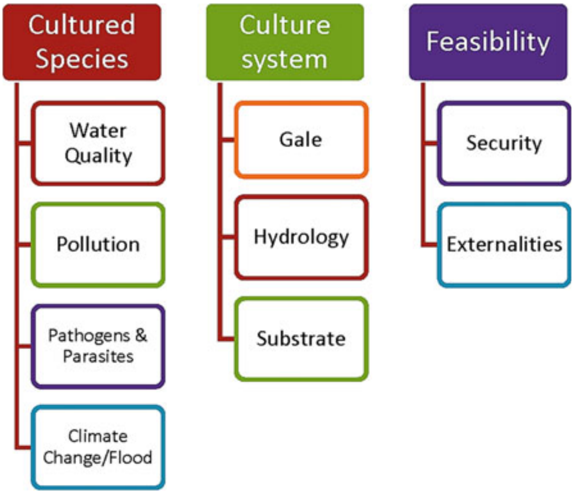
According to Shang and Tisdell (1997), sustainable aquaculture as affected by the environment occurs at two fronts: the local or farm level and the wide society level. We categorize threats (Fig. 1.5) from the environment to aquaculture under three broad classes following Lawson (2013).

1.3.1 Threats to Cultured Species

1.3.1.1 Water Quality

Water supply for aquaculture is the most important criteria for siting and location of farm units. However, anthropological activities create a dynamic water quality in

Fig. 1.5 Categories of environmental threats to aquaculture



water bodies that feed aquaculture facilities. Water for aquaculture must have suitable dissolved oxygen, temperature, pH, and low levels of nitrogenous compounds. Unfavourable levels of these parameters demand investment to correct the levels in intake water. Temperature and dissolved oxygen are the most difficult to regulate and would require greater variable cost to maintain.

Discharge of cooling water from power plants into water bodies that serve as water source for aquaculture can affect the temperature of water intake for aquaculture. Temperatures at discharge points can vary but typically range from 12 to 42 °C depending on the region of the world (Langford 1990). Deviations from optimal water temperatures for aquatic organisms lead to changes in respiration and metabolism with sub-optimal levels of water quality parameters causing stress and its related consequences (Lawson 2013). Temperature tolerance in fish runs from the inhibiting level through the loading level to the lethal level and finally the lethal threshold (Coutant 2013). When water temperatures in water bodies holding cages for aquaculture change drastically, supporting and beneficial organisms in the ecosystem may be eliminated in favour of organisms that may be detrimental to the stock under culture and vice versa (Echols et al. 2009). Lake stratification period during the summer has been found to be extended by the combined effects of thermal pollution and climate change (Kirillin et al. 2013) with nuclear and coal fed power plants contributing half the quantity of heat dumped into rivers and lakes (Raptis and Pfister 2016). Increased water temperatures lead to increased metabolic rates in aquatic organisms and this happens in an environment that is oxygen deficient since warm water contains less oxygen and places great stress on the organisms.

Domestic and industrial waste accumulation in coastal areas as well as highly populated settlements tend to make the environment unsuitable for aquaculture by serving as either direct drivers of toxicity or indirect drivers through the depletion of dissolved oxygen as a result of decomposition of organic matter (Gesamp 2001). Hypoxic conditions in the Gulf of Mexico have been linked to eutrophication caused by nutrient release through the Mississippi River (Rabalais et al. 2007; Bianchi et al. 2010).

1.3.1.2 Pollution

Pesticides, heavy metals and organic compounds that are released into the environment are a threat to aquaculture organisms given the fact that they can alter basic physiological functions, damage anatomical structures and can also lie latent and get passed to humans that consume fish. Echols et al. (2009) had rightly observed that aquatic pollution resulting from heavy metals, hydrocarbons, radioactivity and synthetic organic chemicals occur as a result of human negligence or inappropriate use and disposal of waste.

Tsangaris et al. (2010), reported a reduction in acetylcholinesterase (AchE) activity in mussels caged in sites close to agricultural land as well as sites impacted by urban and industrial waste suggesting some level of neurotoxicity. Similarly, Cappello et al. (2013), reported gill tissue damage in mussels raised in cages placed in water impacted by anthropogenic factors hence a form of environmental distress was affecting the mussels. Salmon feed has been indicted in the persistence of organochlorine compounds in salmon with fish flesh having the highest concentrations as against fish oil and fish feed suggesting bioaccumulation of these compounds in the fish (Jacobs et al. 2002). This is further strengthened by the report of Hites et al. (2004) that farmed salmon contained higher levels of organochlorine compounds than wild salmon. However, recent reports by Masci et al. (2014) and Nostbakken et al. (2015) have shown that levels of organochlorine compounds in farmed fish have declined but fish feed still remains a source of the pollutants getting into farmed fish.

1.3.1.3 Pathogens and Parasites

Disease and parasite infections occur as a result of interactions between the host, the pathogen/parasite and the environment. The prevalence of a pathogen in an environment does not necessarily translate to disease infection. Several predisposing factors relating to each of these factors that cause disease are discussed by St-Hilaire et al. (1998).

Marine invertebrates have been thought to be agents of bacteria transmission to aquaculture organisms (Olafsen 2001). Cryptobiosis is a parasitic infection that is transmitted to salmon in hatcheries through the leech as an intermediate host that is present in intake water (Guo and Woo 2009). Bryozoans have been reported as the carriers of the myxozoan parasite *Tetracapsuloides bryosalmonae* which causes proliferative kidney disease (PKD) in salmon and trout (McGurk et al. 2006). The vertical transmission of Myxosporea and Malacosporea in Bryozoans has been demonstrated by Morris and Adams (2006). Small and Pagenkopp (2011) gave an extensive review of the reserves and intermediate hosts of pathogens of crustaceans of economic importance and this included the water and sediments, other aquatic animals, algae and biofilm.

1.3.1.4 Climate Change/Flood

Climate change leads to several changes that are critical to both fisheries and aquaculture. These include drought, altered precipitation pattern, intensity of storms, changes in sea temperature, rising sea level, El Niño's and increased inland water temperatures (WorldFish 2007). Climate change has both positive and negative effects on aquaculture. According to Weinert et al. (2016), about 49 species of benthos have lost their habitats in the North sea between 2001 and 2009 while 11 species consolidated their habitats reach. Furthermore, the use of modelling effectively predicted gains in habitats coverage for an invasive mussel species against a native species in Europe while invasive crayfish would lose range in favour of the local species up to the year 2050 (Gallardo and Aldridge 2013). These corroborate the implication as proposed by WorldFish (2007) that sea surface temperature increase can increase aquaculture production but may be obscured by changes in number of species available for culture. Increased temperature of water has been found to affect fish muscle and mechanisms responsible for detoxication as exemplified in *Sparus aurata* (Madeira et al. 2016). Salt water intrusion will also create a shift from freshwater aquaculture species to brackish water species (Williams 2011).

1.3.2 Threats to the Culture System

1.3.2.1 Gale

Marine cage aquaculture is affected by adverse weather conditions which include violent storms, cold weather and strong winds. Storms and winds tend to affect cage structure and can destroy the cage entirely. Waves that build up as wind blows across the surface of the ocean can cause severe damage to cages that are constructed in open areas without wind breaks. Wave heights of 1–1.5 m can be detrimental to small cages (Lawson 2013). Climate change is expected to come with large waves and heavy storms in flood prone areas hence heavy precipitation that will lead to loss of aquaculture installations, increased capital expenditure on stronger cage moorings, pond dykes, reservoir walls and other farm facilities (WorldFish 2007). Computer aided modelling has been used to determine the mooring dynamics (Fredriksson et al. 2003; DeCew et al. 2010) and the movements as well as load impacting cages (Colbourne and Allen 2000).

Inland water based cage aquaculture (Photo 1.6) is also prone to effects of adverse weather conditions. Excessive as well as inadequate water flow has been

Photo 1.6 Tilapia cage farming in Chao Phraya River, Thailand

found to damage cage structures hence heavy economic losses in Northern Thailand (Lebel et al. 2015). Interestingly, there is a moderately positive correlation between wind velocity and concentration of 2-methylisoborneol (an off-flavour causing compound) in catfish pond waters in the United States (Hurlburt et al. 2009).

1.3.2.2 Hydrology

Water current tends to impact cages through increased loading on the cage and the supporting structures, and the effects of currents are far greater than waves (Huang et al. 2008). Although Lawson (2013) proposed that tidal currents in the range of 0.1–0.6 ms^{-1} was favourable for cages and values greater than 1 ms^{-1} (Huang et al. 2008) being totally destructive, Lader et al. (2008) reported that currents of 0.13 and 0.35 ms^{-1} caused cage volume reductions of 20 and 40%, respectively and that location influenced the volume reduction. Current distribution on the water surface is vital to stability of cage structures (DeCew et al. 2010) and several models have been estimated to determine design parameters that will ensure the stability of cages under strong currents (Zhao et al. 2007; Kim et al. 2014; Cui et al. 2013). The tested models have indicated that the tension on mooring lines is directly proportional to wave height and wave period with a recommendation on the use of square nets

(Cui et al. 2013) while (Zhao et al. 2007) posited that diamond shaped nets are better considering possibility of a reduction in structure size ratio.

Climate change is expected to cause changes in rainfall pattern, volume and hence affect water volume in water bodies leading to increase or decrease in water depth depending on the area affected. The use of cages and net pens in aquaculture will be affected since these structures depend on water level. Water exchange in floating cages is effective at depths with the cage bottoms off the floor at low tide (Lawson 2013).

1.3.2.3 Substrate

The choice of culture systems depends on available substrate. Changes in substrate type are expected under climate change scenario given increased precipitation, flooding and sediment flow into water bodies. Net pens are better constructed on muddy substrates while floating cages perform better on hard rocky surfaces (Lawson 2013). However, changes in substrate materials will tend to affect the culture system's performance as rightly observed by Tidwell and Coyle (2008). Boyd (2012), summarised the basic soil properties and the processes they affect in aquaculture ponds. Soil particle size and texture, organic matter content and sediment depth tend to affect the integrity of the pond as a holding facility.

Pond culture in areas with acid sulphate soils is affected by low pH levels due to oxidation of iron pyrite catalysed by *Thiobacillus* in the upper level of the soil when exposed to air (Boyd 2012; Yoo and Boyd 2012). Acid sulphate soils have been reported to affect aquaculture ponds in Thailand and the Philippines with pH values of 3.9–4.4 and 3.4–6.3 (Singh 1980), respectively. Harvesting operations that require pond drainage tend to expose the pond bottom soil to air hence oxidation leading to increased acidity and lower pH levels. Runoff from exposed dykes with oxidized iron pyrite into the pond will also lead to acidic condition in the pond (Mahmood and Saikat 1995).

The cost of remediation of acid sulphate soils for aquaculture is the basic problem posed by this environmental factor to aquaculture system construction (Hechanova 1984). Currently, the methods used for remediation and management include: Inundation/drainage cycles with seawater, liming, barricades and induced oxidation (Hechanova 1984; Sammut 1996). However, wise use of site selection criteria remains the best option if cost avoidance can be made else mitigation is needed when land propriety cannot be changed.

1.3.3 Threats to Aquaculture Feasibility

1.3.3.1 Security

Poaching and predation are two major issues that affect aquaculture facilities with origin from the environment. Cage aquaculture is prone to vandalism and poaching

(Ranchan 1984; Beveridge 2008; Parker 2011). This affects the profit margin of aquaculture ventures and is therefore a serious threat to aquaculture sustainability. Several measures have been proposed to curb poaching including row boats with barbed wire to pick up poaching nets, fencing, canine surveillance, and natural barriers in the form of trees. Poaching of oysters has recently been reported in Maryland in the USA (Lessner 2015; Calvert 2016). Predation can also be prevented by using nets to cover the pond tops to prevent entry by birds as well as around the sides to trap reptiles like monitor lizards and snakes.

1.3.3.2 Externalities

These are factors that are associated with economics and society with associated relevance to aquaculture itself. Support facilities for aquaculture such as feed manufacturing, economies of scale, foreign and local markets, policy and legal requirements, and allocation of space are among other factors.

Policy makers, aquaculture entrepreneurs and ancillary occupations seem to be disconnected hence aquaculture production is not at its peak or close to its potential (Krause et al. 2015). Aquaculture policy development must carry the people along and focus on national interest, rational use of resources and market driven development. Policies need to encourage the use of environmentally friendly production technologies (Olalo 2001). However, in cases where policy making does not involve the end users of the policy, a mismatch is created. Krause et al. (2015), argued that the divide between policy and end users tends to create inequity, mismatch between gains and needs leading to food insecurity and health issues. In China, the policy drive of the government focused on markets and information in the late 1990s (Huang et al. 2001). A policy framework and process that considers the environment, society and the economy with precautionary recognition of impacts within the social sphere, carrying the people along in policy making and re-evaluation process with due regards for production capacity and prevailing global demand, and feedback mechanisms that examine and depict the communal aspects of aquaculture in a multi-dimensional manner is ideal for sustainable aquaculture development (Krause et al. 2015). The policy interventions necessary for assimilation of aquaculture technology can be determined by using models (Nobre et al. 2009; Slater et al. 2013).

Legal issues relating to aquaculture development involve licensing, competing use of space and local regulations pertaining to use of land and water surfaces. Stakeholders in the marine finfish aquaculture industry in Europe advocate for greater representation and share in benefits and issues with ability to influence decisions within the social context (Ertor and Ortega-Cerda 2015). The tourism sector has been found to compete stiffly with coastal aquaculture in Europe (Hofherr et al. 2015).

The development of local and international markets in tandem is ideal for aquaculture development in order to encourage small holder aquaculture and ensure food security. However, a lopsided approach that considers foreign markets will harm national food security situation. The development of support industries that service the aquaculture sector is also vital in the quest for sustainable aquaculture (Lawson 2013).

1.4 Site Selection and Carrying Capacity Assessment of Aquaculture

Sustainability of aquaculture with consideration of ecological and environmental impacts will be achieved using several approaches. One important approach is proper siting of facilities so as to mitigate negative impacts. A combination of site selection, proper facility design, construction and management will form the bedrock for sustainable aquaculture. Policy is also vital in this regard as it ensures regulation of entry into the business of aquaculture and also creates specific locations that are suitable and capable of absorbing the effects of aquaculture on the environment. There is a paucity of regulatory framework for environmental quality in the aquaculture industry in most nations (USAID 2013).

The peak loading of aquaculture organisms that can be supported by the environment without deleterious effects on the stock, the culture system and the environment holding the system is what is referred to as carrying capacity (Stigebrandt 2011). Within an aquaculture system, the biomass under culture presents scenarios of an input-output relationship with inputs being additive and outputs being subtractive. According to Sowles (2003), there is a cultural dimension to carrying capacity hence it tends to have a dynamic nature. Carrying capacity of an environment for particular nutrients will be lowered with increasing levels of the nutrient but tends to increase with sustained removal by flora and fauna subject to their ability to reproduce and rebound from stressful conditions.

Acceptable levels of water quality within water bodies that surround an aquaculture site is the major determinant of quality of effluent being discharged by the aquaculture firms considering the stock under culture (Stigebrandt 2011). Viability and profitability of aquaculture ventures are linked to the level of environmental impact they have (Gegner and Rinehart 2009) hence production, livelihoods and competition for resource use must be in equilibrium.

1.4.1 Application of Site Selection and Carrying Capacity in Aquaculture

There is an inextricable link between policy and scientific evidence which in this case involves the determination of standards that are meant to regulate aquaculture through scientific processes to avoid exceeding carrying capacity. Determination of limits and standards using cutting edge ideas and contrivances that are dependable is the first step in the process of policy formulation that is closely followed by a political phase (Stigebrandt 2011). Aquaculture can be limited by space and competitive use of land (Hofherr et al. 2015) hence site selection must consider both carrying capacity and available space (Kapetsky and Aguilar-Manjarrez 2013).

According to Ross et al. (2013), the aim of carrying capacity assessment is achieved when there is no undesirable change in the ecosystem resulting from aquaculture while maximum set limits of production are executed with resultant social satisfaction considering competing interests within the given environment. Sustainability is therefore achieved since communal satisfaction is achieved through sufficient economic benefits using technologies that are eco-friendly while also providing room for other resource users. Aquaculture installations can be conveniently installed at capacities that are in tandem with the carrying capacity following its determination. Carrying capacity also serves as a tool for aquaculture planning, determination of suitable aquaculture zones and areas of appeal to aquaculture.

1.4.2 Theoretical Basis/Framework/Approach

Considering mollusc aquaculture, Inglis et al. (2000) gave four classes of carrying capacity: production carrying capacity, physical carrying capacity, social carrying capacity and ecological carrying capacity. Further explanation was provided by several authors considering the fact that the farm is a small unit within the larger environment that is subject to social and cultural norms (McKindsey et al. 2006; Byron et al. 2011; Ross et al. 2013).

There is both a temporal and spatial scope to site selection and carrying capacity in aquaculture planning and regulation. Activities pertaining to aquaculture planning and development progress spatially and temporally from identification of potential through sectoring or zoning and selection of the site to final implementation of aquaculture activities. Site selection is the final step in the process and it has the least scope with mapping of zones being intermediate and identification of potential having a broad spatial coverage.

Sustainability ought to drive aquaculture development with ecosystem stability being drawn from carrying capacity. This therefore means that all the categories of carrying capacity must be considered together within a given space over time to achieve ecosystem stability as proposed by Kapetsky and Aguilar-Manjarrez (2013). The FAO (2010) accentuated three basic principles of an ecosystem approach to aquaculture to include: use of all ecosystem functions and services without probability of becoming unsustainable, factor in livelihoods of all stakeholders with concern for improved wellbeing and finally reckon with activities, policies and targets of other productive sectors.

1.4.3 Carrying Capacity and Site Selection: When Is the Right Time to Apply These Tools?

Increased demand for aquaculture space is expected to occur in the future considering fast growth of the sector particularly in Asia and Africa with resultant effect being the use of virgin coastal and continental shelves hence altering the ecosystem services and products derivable. Local factors concerning the ecological integrity of a site and market volume are two conventional criteria that drive site selection for aquaculture. The need for proximity to infrastructure and associated services for aquaculture is a driver for the location of aquaculture facilities with impacts that will affect the environment, access to transportation and markets (Ross et al. 2013). The short term nature of this planning strategy will stifle aquaculture development even more so because it has a local spatial coverage with greater extent of effects on sustainability within the immediate environment.

Carrying capacity is considered all the way through the site selection process right from estimation of potential with emphasis at the point of actual siting. This follows temporal and spatial dimensions since the process must start at a given time and consider an entire gamut of available space before narrowing down to the actual spots that are suitable for aquaculture (Fig. 1.6). Advancements in aquaculture systems and introduction of novel aquaculture species is an on-going process hence carrying capacity estimation has to go hand in hand to suit the new system or species. In addition, expansion to new sites using old species still necessitates determination of carrying capacity.

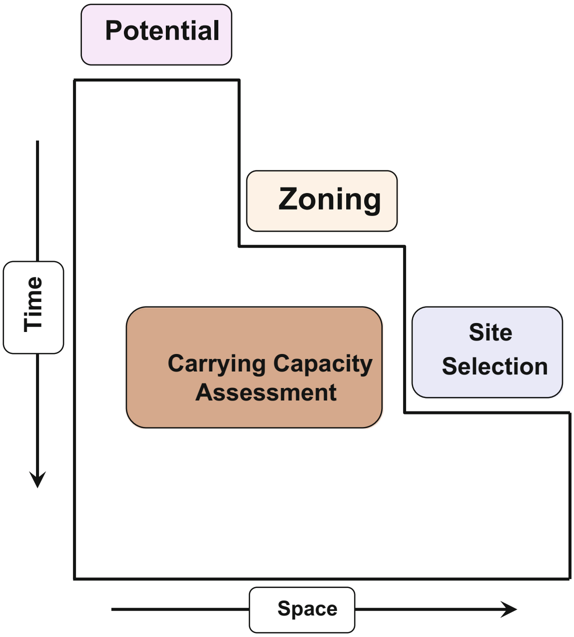


Fig. 1.6 Spatial and temporal progression of aquaculture development activities

1.5 Aquaculture Hazard and Risk Analysis

1.5.1 Concept of Risk

Risk encompasses three basic concepts which according to Arthur (2008) includes uncertainty, probability and impact. Therefore, risk in aquaculture involves the possibility for an undesired outcome from production activities alongside damages that would occur. The presence of a factor, substance or object that causes or portends danger is referred to as a hazard (Johnson 1998). Biological nature of aquaculture systems is a hazard that brings about price uncertainty (Flaten et al. 2011).

Francis and Shotton (1998) considered the definitions of risk as covered under two points of view: the probability and the decision theory, the bottom-line being a consequence or effect of a situation and how large this can be. Surrounding the probability and scale of an undesirable event is the concept of uncertainty (Hargrave et al. 2005). A risk can be quantified if the probability of the undesirable event is known. Certain uncertainties can be reduced via accumulation of knowledge and data while others have a huge scale of uncertainty especially those related to natural occurrences (Gesamp 2001; Hargrave et al. 2005). Generally as issues move from the farm scale to a broader regional and national scale, predictability becomes difficult (Hargrave et al. 2005). McDaniels et al. (2006) have shown that decision making for risk management in the salmon aquaculture industry occurs at four different scales namely, local scale that deals with zoning and site selection, regional scale that deals with operating licences and monitoring of production, national scale that is involved in regulation, and finally the international scale that is quite different considering the absence of regulatory structures. While McDaniels et al. (2006) have proposed a value based decision making tool that is based on stakeholder opinion, the scientific community is divided as regards accepting public opinion in decision making (Young and Matthews 2011). This notwithstanding, the value based decision tool of McDaniels et al. (2006) encompasses five objectives that address sustainability and decision making.

Risk according to Sethi (2010) is the probability that a divergence from an anticipated outcome will lead to an undesirable effect with risk itself being a potential, while realised risk is risk that has been actually experienced. Considering magnitude and consequence, the World Organisation for Animal Health sees risk as the likelihood of an unpleasant circumstance and the magnitude of the unpleasant effects whether biological or economic on both human and animal wellbeing (OIE 2015). The concept of probability of occurrence and consequent losses was also highlighted by Olanrewaju et al. (2013). Although the presence of farmed salmon impacts wild trout in terms of infection with salmon lice, Taranger et al. (2011) opined that greater probability of occurrence of salmon lice in wild trout is not entirely explained by biomass of farmed salmon under culture. Brun (2013) sums up risk as an artefact with a subjective insight that is designed to help us grasp the meaning of danger and also be able to grapple with it considering the limitations of our environment, upbringing and culture (Olanrewaju et al. 2013).

Risk permeates fisheries management considering the presence of uncertainty, fluctuations, paucity and multiple goals (Sethi 2010; Olanrewaju et al. 2013). In aquaculture, uncertainties may include but not limited to diseases, natural disasters, poor outputs, breakdown of equipment, sediment accumulation, nutrient enrichment, exhaustion of dissolved oxygen, mortality, escapes, bloom of deleterious algae, conflicts on resource use, and bad water quality (Clark et al. 2010; Hargrave et al. 2005; McIntosh 2008; Tlusty 2002). Risk from aquaculture according to (Reantaso 2008; Ezekiel et al. 2011) include changes in habitat structure, pollution, climate change, genetic issues, food safety, and occupational risks. The scope of these risks is large since it affects the environment, the people and their wellbeing (Reantaso 2008). However, application of risk management is advocated as the best way to avoid loss and fritter (Secretan et al. 2007).

Ezekiel et al. (2011) delineated risk as either from aquaculture to the environment or from the environment to aquaculture hence effectively bringing in the perception of risk from different perspectives. Risks relating to production and marketing are vital for an aquaculturist while people who also rely on the same natural resources as the aquaculturist will view aquaculture as a risk within the environment. However way it is perceived, risk is associated with activities and outputs. Hazards affecting aquaculture development may come from biological, environmental or economic sources (see: Reantaso 2008; Ezekiel et al. 2011; Subasinghe et al. 2012; Swaminathan 2012).

1.5.2 Theoretical Framework of Risk Analysis in Aquaculture

The main goals of risk analysis in aquaculture are the identification and assessment of risk so that adequate mitigation can be directed at the risks in such a manner that benefits both the aquaculture enterprise as well as the society as a whole. To adequately mitigate risk, threat and vulnerability must be quantified so that controls can be applied to minimize risk. Risk management, assessment and communication are three key steps in risk analysis (Yoe 2012) with the addition of hazard identification being important considering aquatic animal health (OIE 2015), but it is important that this step considers the entire life cycle of the animal (Olanrewaju et al. 2013). A different risk analysis process is however proposed by Olanrewaju et al. (2013) to include assessment, screening, evaluation and management with assessment being a qualitative to quantitative process, screening being a specification step, evaluation being a stochastic process and the management step being mitigation. This approach however does not consider communication which is a very important step in the loop. For the purpose of this text, we shall consider four steps of risk analysis (Fig. 1.7).

Hazard identification brings to the fore all harmful objects, substances and conditions so that they can be assessed during the assessment step in order to

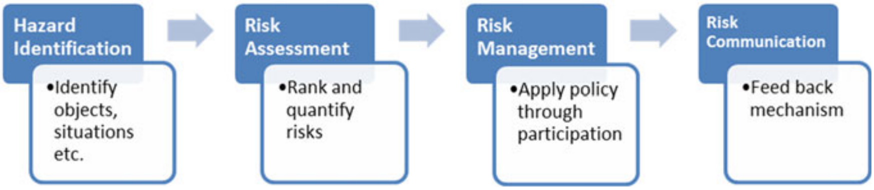
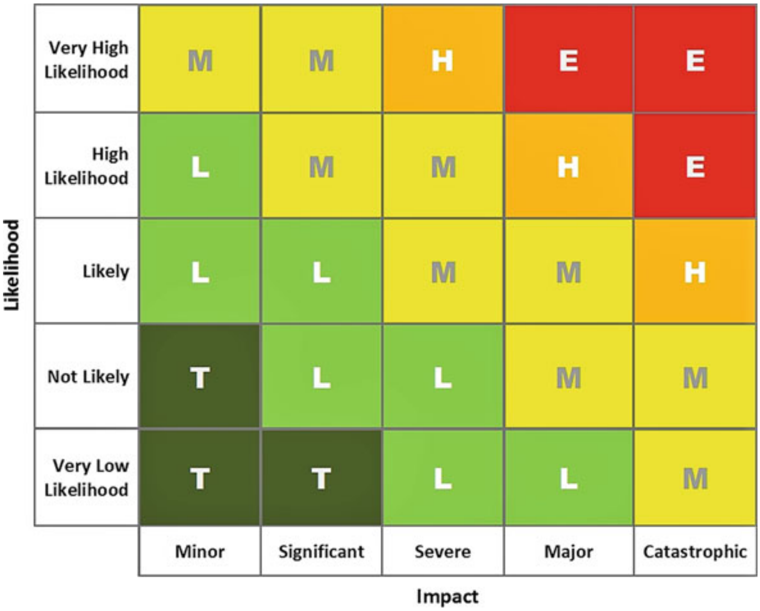


Fig. 1.7 Activities in a risk analysis process

determine qualitative and quantitative aspects of the risks posed by the hazards and therefore be able to make decisions and guide policy formulation accordingly. Hazard identification in aquaculture can be carried out using either robust techniques (Crawley et al. 2003; Wells 1996) or rapid tools (WHO 2003). Robust methods such as the fault tree (Hayes 2002a) and a variant of failure modes and effects analysis as applied to infection (Hayes 2002b) have been applied to estimate hazard from invasive species. The fault tree has been applied to investigate the hazard of introducing GIFT tilapia in Zambia (Lind et al. 2015). The risk management step is a participatory step that looks at all available and applicable policies by regulators and stakeholders with due consideration for social, economic and environmental wellbeing (Hargrave et al. 2005). Mis-matches in the system can be corrected through the risk communication step because it allows for re-evaluation of the process for re-adjustment. Yoe (2012) pointed out that the human mind can be quite good at analysing a situation to reach a decision but there could be pitfalls in human reasoning that necessitate the involvement of several people in the decision making process. It is therefore ideal that employees be involved in the risk management process at the enterprise level so that decisions can be taken through interactions between management and staff.

Risk management is a highly subjective step in the process since it relies on the perception of the risk manager. The risk of aquaculture to the environment and from the environment to aquaculture can be qualified using probability and magnitude. A risk matrix (Fig. 1.8) that is based on colour codes with progression of risk increase either through upward movement or movement to the right was presented by Brun (2013). Hazard identification and the determination of levels of impact and likelihood are vital and must be based on objectives such that the assessment process can delineate the effects of risks on the ecosystem, the environment and socio-economic wellbeing using available tools, conventions and procedures that effectively determine value (Olanrewaju et al. 2013; Aven 2012). The risk appetite of a farm will therefore be a yardstick to determine risk acceptance. The risk matrix will also guide regulatory agencies in the determination of the acceptability of aquaculture socially and environmentally. Magnitude is ranked below impact in the analysis involving the risk matrix hence impact is considered rather than magnitude.

Considering the spatial scope of risks, the risk matrix with its quantifiable probability of occurrence and impact will give us a vivid idea about the actual location of risks at all levels beginning from the farm to the environment, the social



	Minor	Significant	Severe	Major	Catastrophic
Very High Likelihood	M	M	H	E	E
High Likelihood	L	M	M	H	E
Likely	L	L	M	M	H
Not Likely	T	L	L	M	M
Very Low Likelihood	T	T	L	L	M

Fig. 1.8 Risk matrix. After Brun (2013): T = trivial Risk; L = low risk; M = moderate risk; H = high risk; E = extreme risk. Risk level is identified by the intersection of likelihood and consequence. Trivial risk will generally not require significant or specific resource use in its management while low risks can be managed using routine management with proper supervision. Moderate risk requires a timely higher level management intervention with the aid of an action plan and high risk requires ready to implement action plan. Extreme risk can be effectively managed using a detailed plan

and economic scopes. With this, potential effects of aquaculture on the environment such as erosion, loss of ecosystem services, pollution, nutrient loading and increased demand for water will easily be quantified. Application of risk analysis for pathogens, food safety, genetics, ecology, environment and social risks in aquaculture (Table 1.3) can ensure sustainability of aquaculture through a reduced impact of aquaculture to the environment as well as from the environment to aquaculture.

Pathogen risk analysis as applied to import of aquaculture products seeks to determine the presence of dangerous pathogens, the probability of transfer to importing nation, expected impacts of exposure of susceptible organisms, risk associated with each pathogen if products are allowed in, acceptability of risk of each pathogen and lastly, possible entry of aquaculture products with risks at acceptable level (Bondad-Reantaso and Arthur 2008). A concise analysis of risk associated with international trade in aquatic organisms in the Asia-Pacific region is presented by Diggles and Arthur (2010). Food safety risk analysis must first identify the hazards that are associated with the aquaculture product and determine the likely effects of exposure leading to identification of steps for risk management

Table 1.3 Application of risk analysis for sustainable aquaculture

	Hazard identification	Risk assessment	Risk management	Risk communication
Pathogen risk analysis	Determine high risk pathogens	Release assessment, spread assessment, consequence assessment, risk estimation	Risk evaluation, opinion evaluation, implementation/ monitoring	Gather knowledge and ideas, analyse information, pass information
Food safety	Determine zoonotic pathogens, chemicals of clinical importance	Exposure assessment, dose-response analysis, risk characterization	Risk evaluation, risk options, risk management/ review	Documentation of identified food borne risks for producers consumers and aquaculture value chain
Genetic risk analysis	Cultured stock, exotics, GMO, interspecific hybrids, non-selectively bred organisms	Probability of escape, probability of contact, effect assessment	Site location, containment, control reproduction, manage human activity/access	Science-industry meetings, extension service, publication of reports
Ecological risk analysis	Escapes, habitat modification	Qualitative assessments, quantitative assessments	Standards, inspection, prohibitions, permits, cost and benefits	Stakeholder participation, open communication
Environmental risk analysis	Suspended solids, nutrient enrichment, mangrove destruction, water abstraction	Release assessment, exposure assessment, effects assessment	Mitigation, monitoring, compliance	Quantitative aspects of risk, social dimensions, identify differences among stakeholders
Social risk analysis	Failure: farm level, community level, obstruction	Consequence, magnitudes, documentation	Hedging, aversion, attenuation, subsistence	Corporate social responsibility, continuous planning, implementation, observation and action

and subsequent communication. This principle has been utilized in AquaFRAM, a spreadsheet tool designed to estimate food safety and disease risk in aquacultured salmon (Soon and Baines 2012). Genetic risk in aquaculture is connected with introgression between cultured fish and wild stocks considering the fact that cultured fish have either been selectively bred for certain traits or genetically modified. Management of genetic risk will involve two basic approaches: reducing the possibility of escape as well as the ability to reproduce (Waples et al. 2012). In addition, the location of aquaculture facilities, effective containment and human access limits will go a long way to manage risks associated with escapes. A qualitative ecological risk analysis for the introduction of *Litopenaeus stylirostris* into Fiji from Brunei Darussalam favoured the introduction of the species and a critical evaluation of life cycle and habitat also did not portend any danger but competition, pathogen transfer and hybridization were contentious (Bondad-Reantaso et al. 2005).

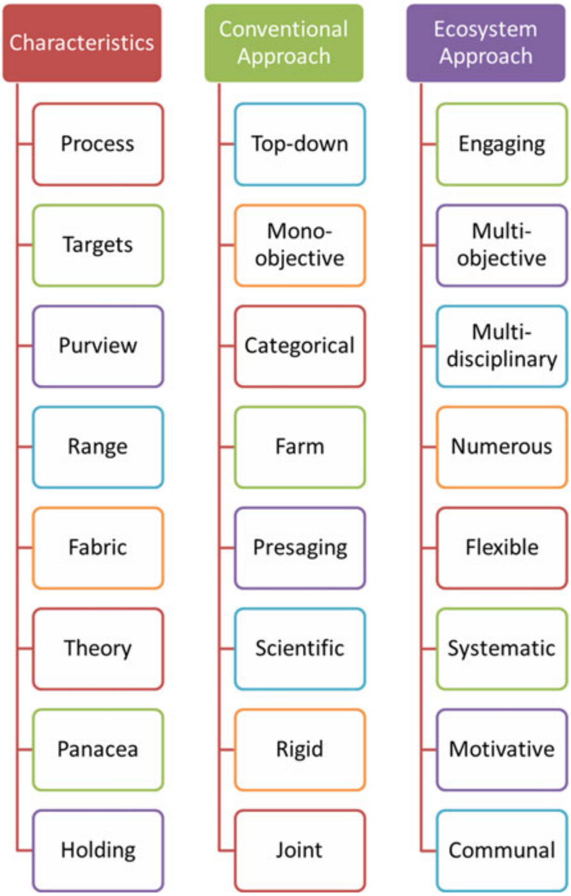
Aquaculture makes use of resources from the environment and also discharges waste into the same environment. As such it is pertinent to determine if site preparation, waste discharge, and water use are hazards that pose a risk. In a risk assessment of the effect of shellfish aquaculture on the environment in Tasmania, the risk of organic nutrient loading was scored with a minor consequence rating with an unlikely rating in terms of likelihood and a low rating in terms of level of risk (Crawford 2001). Social risks resulting from aquaculture are based on hazard of failure of investment as well as obstruction of other commercial activities. The social risk of aquaculture can be assessed considering effects, scope and available records. Loss of investment in aquaculture is a risk that cannot be totally prevented considering the fact that aquaculture deals with biological subjects and the environment. Heavy losses have been incurred by households in poor communities in Vietnam (Luttrell et al. 2004). However, loss can be managed via insurance options with an example provided for the clam aquaculture industry in the United States (Beach and Viator 2008). Aside from insurance, the establishment of subsistence aquaculture facilities provides social benefits (Pillay 1997). Good site selection and planning will attenuate the social risks of aquaculture (Pillay 1997).

1.6 Ecosystem-Based Approach to Aquaculture (EAA)

A strategy that is aimed at blending aquaculture in the wider ecosystem for sustainability, equity and resilience was proposed by the FAO (2010) and dubbed the Ecosystem Approach to Aquaculture (EAA). EAA has created a way to ensure compliance with the Code of Conduct for Responsible Fisheries spatially and at various supervisory levels with regards for national policies, while providing an avenue for regulators and industry operators to work together to ensure sustainability with adequate consideration of the environment, the socio-economic well-being of culturists and goals of regulatory bodies (CAMFA II Policy Brief 2014). The EAA is a shift from conventional management to a method (Fig. 1.9) that puts emphasis on methodology of action with stakeholders having a voice (FAO 2010).

The FAO (2010), prescribed three principles on which EAA must operate that include the use of ecosystem services in planning for aquaculture development and management for sustainability, improved livelihoods of all people in the aquaculture value chain and finally a consideration of other sectors, current policies and expected results.

Fig. 1.9 Distinction between the conventional approach and ecosystem approach (Staples and Funge-Smith 2009)



1.6.1 EAA Planning and Implementation Framework

Planning for EAA (Table 1.4) involves five basic steps:

1. Scoping
2. Identification and prioritization of issues
3. Developing a management plan
4. Implementation
5. Enforcement.

The coverage of implementation according to Staples and Funge-Smith (2009) can be determined by the highest level policy goal in view which could cover national or regional aquaculture, provincial/state aquaculture or just one culture system.

Table 1.4 Framework for planning and implementation of EAA

Step	Function	Input	Outcome
Scoping	Extent of implementation	System boundaries, stakeholders	Coverage
Identification of issues	Expounds the need for intervention	Ecological wellbeing, socio-economic wellbeing, ability to achieve	Impacts and mitigation
Ranking of issues	Prioritization of issues for implementing solutions	Risk analysis	Hierarchy of issues to be tackled chronologically
Define objectives	To develop a working plan for implementation	Information on: use of sites, escapes, pollution, diseases and parasites, access to feeds	Better management
Formulate and implement management plan	Aquaculture development, logical management, adequate surveillance	Legal framework, institutional arrangements, competing livelihood options	Developed human capacity, purposeful research and dissemination, controlled internal and external threats
Implementation of EAA	Optimized feeding, better management, biosecurity, effluent management, environmental impact assessment	Quantitative data	Balance ecosystem with aquaculture
Monitoring and evaluation	Makes review and adaptation possible	Environmental indicators, socio-economic indicators	Reference points of indicators

1.6.2 *Tools for Ecosystem Approach to Aquaculture*

Sustainable aquaculture has a spatial scope therefore, spatial planning tools can effectively separate economic, social and environmental spheres of aquaculture with boundaries clearly defined even though interactions will occur (Aguilar-Manjarrez et al. 2010). Mathematical models are increasingly being used to model carrying capacities. These have the capacity to create replicas of real life situations and give efficient solutions to scenarios which are hitherto not ideal to determine in reality due to cost implications (Ross et al. 2013).

1.6.2.1 Environmental Models

Using baseline and monitoring data, mathematical algorithms can effectively predict environmental response to aquaculture stress. A total of 16 environmental models were considered by the European commission's Ecosystem Approach to Sustainable Aquaculture (ECASA) with each having a scale and a scope that covers species, culture system and motive (ECASA 2008). Carrying capacity, fluxes of matter and energy as well as environmental and ecological indicators serve as means of modelling.

Environmental models (Table 1.5) can be based on either just a single indicator within the environment or by using multiple indicators that include, particulate organic matter, soluble organic matter and chemicals involved in the production process (Southall et al. 2004). Simple linear regression using time series data can be used to estimate environmental capacity while more complex models are useful if there is a lack of data that predates present times hence the use of several of such tools in arriving at an environmental capacity.

Table 1.5 Environmental carrying capacity models

Model	Criteria/input	References
MOM (modelling ongrowing fish farms-monitoring)	Waste dispersion, waste dilution	Stigebrandt et al. (2004), (Stigebrandt 2011)
TRISULA/DELWAQ	Heat dispersion, sediment transport, water quality, heavy metals	Southall et al. (2004)
CORMIX	Near mixing	
CORMIX + WASP + QUALBAVI	BOD, DO, faecal coliform, N, P	
Ecopath + Ecosim (EWE)	Mass balance of trophic relationships	Christensen and Walters (2004)
Fuzzy models + GIS	Physical environment, pollutants	Navas et al. (2011)
Shellsim	Clearance rate, particle retention efficiency, filtration rate, absorption rate, rejection rate, ingestion rate, absorption efficiency	Ferreira et al. (2008)
EcoWin2000	One, two and three dimensional scaling, water exchanges, hydrodynamics (not appropriate for farm scale modelling)	
BEAST (benthic environmental assessment sediment tool)	Sediments, particle size, erosion	Walker et al. (2014)

1.6.2.2 Spatial Models

Determination of the worth of land and subsequent allocation for productive activity are very important steps in resource use and development. However, sustainability of productive and extractive use can only be determined using procedures and applications that will adequately guide decision as well as predict outcomes based on usage scenarios and available physical data (Table 1.6). This according to Kapetsky et al. (2007) can be achieved using GIS (Geographic Information System) tools. With the application of geo-spatial tools, sustainability friendly policies are now being made (Morgan and LaFary 2009).

The combination of planning and site selection is sine-qua-non to sustainable aquaculture. Information is critical to identifying suitable sites that have the capacity to hold aquaculture facilities. Comprehensive understanding of the environment, social, economic and political factors forms the bedrock of analysis of sites for aquaculture suitability. Unsustainable production would be the bane of ill-selected sites with impacts on the environment, livelihoods and the organisms under culture (Naylor and Burke 2005). Site selection that involves the use of GIS models are effectively done using logical analysis of spatial data to guide assessment of available resources and their management (Ragbirsingh and De Souza 2005; Longdill 2007).

Multi-Criteria Evaluation (MCE) is typically a multivariate analysis method that involves the use of various criteria and variables to arrive at the best combination of variables to achieve the best results desired. The combination of GIS and MCE was proposed by Carver (1991) and has been applied in the determination of potentials and suitable sites for carp culture (Salam et al. 2005), Japanese scallop (Radiarta et al. 2008), mussel (*Perna canaliculus*) (Longdill et al. 2008), giant river prawn (Hossain and Das 2010), Pacific oyster (Silva et al. 2011) and for general carrying capacity evaluation and site selection (Hossain et al. 2009; Dapueto et al. 2015).

Table 1.6 Steps for a spatial model estimation

Step	Description	Activity category
Goal identification	Quantifiable, practicable, germane, precise, temporal limit	Non-GIS activity
Identify criteria (factors and constraints)	Quantifiable else use proximates Details required determine criteria	
Align factors and criteria	Create common scale for factors Use fuzzy function to align criteria scores Decide functions for each criterion	
Assign weights to factors	Ranks, rates, pairwise comparison	
Map the criteria	Weighted linear combination	GIS activity
Confirm results	Determines reliability of results – Sensitivity analysis – Ground verification	

A combination of regulatory and social barriers, MCE and the Farm Aquaculture Resource Management (FARM) model was used by Silva et al. (2011) for site selection in areas with poor data for shellfish aquaculture.

GIS models are supported by decision making software that elucidates better judgement and decision making considering choices. Examples of software currently available include IDRISI, CommonGIS and ArcGIS (Nyerges and Jankowski 2010; Fisher 2006). ArcGIS does not have the robust capacity for MCE analysis but according to Nyerges and Jankowski (2010) weighted summation overlays give it the capability, while (Eldrandaly 2013) utilized component object model (COM) technology in tandem with ArcGIS to achieve MCE for site selection.

1.6.2.3 Socio-economic Models

There is no fully developed model for determining the social carrying capacity of aquaculture. Byron et al. (2014), utilized Ecopath, a mass balance model and IMPLAN, an input-output economic modelling software to integrate carrying capacity of bivalve aquaculture with social and ecological aspects to provide direction for policy that will ensure sustainability.

Models that have an economic and social approach to agricultural activity location dates back to 1826 with the von Thunen model which was premised on some assumptions that included isolation and independence, a surrounding of empty land around occupied space, flat terrain without obstructions, consistent climate and soil quality, self-distribution of produce without roads, and a goal for profit maximization by farmers (Chorley and Haggett 2013). Modifications to this model have been presented by various authors but according to Wilson and Birkin (1987), two critical shortcomings need to be addressed: the constraint that all products are sold at the nearest market and secondly the static nature of the model. Furthermore, Chorley and Haggett (2013) argued that the Thunen model required modification to remove its partial equilibrium status, account for non-economic factors with expanded scope and finally consider the varying scales of the central town.

Input-output models and spatial equilibrium models are a group of geographical location models that consider factors of production, consumers and the producers along the chain with competitive advantage differentiating regions. Chorley and Haggett (2013), advocated the use of the spatial equilibrium models as the most suitable for locating suitable sites for agricultural production provided there is adequate data.

Application of partial equilibrium models in terrestrial agriculture is widely reported. The need to improve these models using innovative additions and modifications has resulted in various versions of models. One common partial equilibrium model is the Common Agricultural Policy Regionalised Impact System (CAPRI). Espinosa et al. (2016), introduced structural changes in specialization, region and size of the economy into this model at the farm level and discovered that structural changes affected the area under cultivation, number of animals reared and the size of farms distributed considering their economic size hence the need to consider farm structural changes in policy decisions.

Land use change is driven by factors that are inherent in the society as well as the environment and it has a spatial outlook. The local changes in land use can be insignificant but regional and global land use changes are significant (Heistermann et al. 2006). Land use patterns have an effect on sustainability and are determined to a large extent by societal culture, livelihoods and appetite for commodities that require large expanses of land. This underscores the need for models that will help us understand the consequences of changes in natural and socioeconomic factors on production, exchange of goods, demand and prices of agricultural markets (von Lompe 2003). Economic models that deal with land use aim to elucidate the demand-supply pattern of production sectors with high demand for land and they are basically equilibrium models (Heistermann et al. 2006). Detailed descriptions of economic models are provided by Balkhausen and Banse (2005) and Heistermann et al. (2006). Economic models are classified under two categories: partial equilibrium models (PE) and computable general equilibrium models (CGE). The PE models are dynamic with a global scope, and consider other markets that are not agricultural as exogenous, hence there is homogeneity of goods traded. However, CGE models differ in the consideration of non-agricultural markets as endogenous, have a static approach, and consider trade as a bilateral interaction (Balkhausen and Banse 2005; Heistermann et al. 2006). The Global Trade Analysis Project (GTAP) model (a CGE Model) was combined with a biophysical model by Van Meijl et al. (2006) to predict the availability of land for agricultural activity in the EU without shortages between 2006 and 2036.

Merging geographic and economic models may be ideal for aquaculture judging from the insights gained in the application to terrestrial agriculture. A combination of CAPRI and CLUE (Conversion of Land Use and its Effects) have been reported to create robust results that link economics and policy (from CLUE) to agricultural production, income and price structure (from CAPRI) under the influence of land use dynamics (Overmars et al. 2013; Britz et al. 2011). A downscaling model that relied on the census of farms as well as land use type in Switzerland produced a reasonable measure of the spatial motif of use of land for agricultural purpose (Gärtner et al. 2013).

1.6.3 Aquaculture Governance, Planning and Management Practices

Policies, laws and their enforcement must be transparent with accountability hence in the absence of corruption, there will be development through a well-controlled economic environment aided by support from citizens with the will to grow. The difference between the developed and developing countries according to Hishamunda (2010) lies in good governance that creates conducive environment for wealth creation. This is also true for economic activities within the same productive sector (Hishamunda et al. 2014). Poverty is detrimental to the environment because it causes people to rely heavily on ecosystem services to the detriment of the environment hence good governance of aquaculture will prevent competition for resources, pollution and bad product quality while upholding human and social security (Hughes and Rose 2011).

Weak aquaculture governance is a threat to the application of the ecosystem approach to aquaculture because its absence creates room for bio-insecurity, poor quality of products, competition and conflict over aquaculture sites, lack of adherence to international standards and little or no trust from the communities (Hishamunda et al. 2012). Governments must ensure that there is conducive environment for aquaculture in the midst of market failure using aquaculture policies that create secure rights to property, encouraging market environments that have contract enforcement and small scale aquaculture ventures at its core and all driven by economic stability, effective research and extension and political security (Hishamunda et al. 2012). These according to Lent et al. (2008) will ensure a stable polity considering economic and social wellbeing. Gender inclusive policies that allow women equal participation in economic activities is important in the drive towards sustainable development (UNWomen 2014). The emerging role of women in the productive sector of the economy in non-OECD countries has been identified especially in export oriented business (OECD 2008). A gender sensitive aquaculture governance is also critical to sustainable aquaculture since the views of rights and their definitions differ between the genders (WorldFish 2011).

According to Hirst (2000), governance is the driving force behind activities, steering them in the direction they ought to go with appropriate controls so as to achieve set deliverables. Governance in the view of the Canadian Institute of Governance (CIG) is the determinant of possession of power to make decisions, voice concerns and show accountability (CIG 2016). From the foregoing, governance is adaptable to sections of society as well as economic groups within the society considering the people involved as stakeholders. The ecosystem approach to aquaculture is an all-inclusive approach that considers the stakeholders hence it is linked to governance and would create a sense of belonging and ownership among them that will lead to maximum impact from total participation.

The planning, management and control of aquaculture, using democratic principles and full participation by stakeholders in order to achieve sustainable livelihoods, social and environmental wellbeing can be referred to as aquaculture governance. However, issues such as aquaculture site availability, supporting inputs, increasing investments in marine aquaculture sector, effects of aquaculture on the environment, technology adaptation and access to finance and credit must be addressed clearly if aquaculture governance is expected to make an impact (Lent et al. 2008).

1.6.3.1 Making Aquaculture Governance Work

Bevir (2012) identified the overlapping and conflicting nature of aquaculture governance and has advocated a Deming's wheel approach to its implementation. According to the Asian Development Bank (ADB), there are four basic principles behind good aquaculture governance: accountability, inclusive participation, regularity and openness (ADB 1995). There are six indicators of governance as presented by the WorldBank (2015). These indicators presented by the ADB and the World Bank were harmonized by Hishamunda et al. (2014) as: accountability for actions, effectiveness/efficiency in dealing with issues, equity between people and predictability of actions (Table 1.7). Aquaculture governance must consider the role of gender in aquaculture as well as changes in livelihoods. Aquaculture has been reported to have a negative effect on the livelihoods of women in the fishing communities of West Africa due to excess work load and loss of livelihoods (Trottier 1987). For aquaculture to be sustainable, its governance must strive to close gender gaps in activities such that there is equity, increased access to resources by women and elimination of gender effects in policy implementation (Scott and Wilde 2006). Policy planning must be participative (FAO 2008) and address gender constraints relating to access to land, resources and capital (Trottier 1987) hence aquaculture governance must be participative, have representation from all relevant stakeholders, and be responsive to their needs.

1.7 Aquaculture Certification and Standards

A third party nonaligned assessment of quality standards that is aimed at confirming claims by a firm of meeting standards is referred to as certification. Standards are actually sets of collectively recognized keys that are beneficial to the aquaculture enterprise, the environment and the society. The setting of standards, endorsement and application of certification, designation of activities and outputs are the crux of certification. The major components in an aquaculture certification would include: food safety, social responsibility, animal welfare and environmental sustainability (Lee 2009). The credibility of certification depends on transparency and application of the scientific approach through integrity and accountability for big and small aquaculture enterprises. Traceability is also an important factor for certified products hence records of product movement is important so as to ensure responsible trading.

1.7.1 Challenges to Sustainable Aquaculture—The Quality Certification Perspective

Small holder aquaculture is at risk of exclusion from the globalization of aquaculture trade due to several reasons as highlighted by Subasinghe and Phillips (2007)

Table 1.7 Applying the principles of aquaculture governance with gender sensitivity

Principle	Outcome	Poor practice	Meeting and improving requirements
Accountability	• Certainty • Reduced graft	• Decisions by officials alone using dubious guidelines • Appeal of decisions is impossible • Scientific information is hardly valid	• Greater openness by regulators and industry • More criteria for transparency • Revelation of perks and outlay of aquaculture
Effectiveness/ efficiency	• Worthwhile service delivery	• Excessive governance • Opposing regulations • Extended red tape in license issuance • Mono-directional contexts of decision making • Low amplitude to monitor and enforce regulations • Insensitivity of communities and stakeholders	• Achievement based management system • Subject regulations to cost-benefit analysis • Expanded participation • Shape capacity
Predictability	• Curtailed risk and transaction costs • Inter-convertible property rights easing loan access	• Enigmatic property rights • Short-term licensure • Decision on site selection is based on rent seeking	• Make property law aquaculture friendly • Open and pellucid criteria and procedures
Equity	• Gender inclusive income and regional distribution	• Short term leases and associated short term objectives • Greater influence by large farms over small farms	• Spur female license bids • Uniform access to credit across genders • Tractability as panacea for license renewal
Participation	• Upsurge in acceptance and conformity • Cut down enforcement costs • Foment trust for aquaculture • Upsurge in demand and consumption • Use of aboriginal knowledge	• Reclining attitude of government officials • Exploiting decision communication process	• Effective communication between stakeholders and officials • Stimulate interest of women • Pass information on advantages of aquaculture and aquaculture products

(continued)

Table 1.7 (continued)

Principle	Outcome	Poor practice	Meeting and improving requirements
Gender representation	• Consider needs of women	• Stakeholders devoid of women • No female representation in regulatory agency	• Policies that fight discrimination and creates equal opportunities in public service • Affirmative action is supported in policies and legislation
Gender responsiveness	• Policies should have ranked needs of women	• Policies and activities in aquaculture that are not gender friendly	• Standardized and transparent methodology considering issues concerning women in aquaculture • Potent legal framework for women

Adapted from Scott and Wilde (2006), Hishamunda et al. (2014)

that include requirements for market access, risks and costs involved in meeting quality standards in the production process. The suitability of certification for small scale aquaculture is in doubt as pointed out by Marschke and Wilkings (2014) hence a deviation from the recommendation that certification schemes should be pro-small scale aquaculture (FAO 2011b). Standards are mostly for high value species that are popular in the western markets hence a very low share of market from developing countries (Jonell et al. 2013) with a lot of questions bothering on fair trade begging for answers (Lee 2009). In addition, the upsurge in eco-friendly certification schemes has been dubbed as modern day extra-territorial conquest (Vandergeest and Unno 2012). However, Global GAP has reported the certification of small holder Pangasius farmers in Vietnam, which was achieved as a result of collective effort (GlobalGap 2014). These challenges can be categorized (Table 1.8) as social, environmental/ethical, and financial challenges.

1.7.2 Certification Criteria for Sustainable Aquaculture

Sustainability is in itself not a quantifiable variable and therefore depends on indicators to identify its direction (Lee 2009). At both national and international levels, the aquaculture value chain is guided by regulations that are particularly targeted at food safety, disease control and conservation with a strong bias for international trade in processed aquatic organisms hence factors such as environmental and socio-economic wellbeing have become open to independent certification for compliance and responsible management (FAO 2011b). A summary of the rationales and relevant criteria for meeting food safety, animal welfare, social

Table 1.8 Challenges of certification and quality standards on small holder aquaculture

Challenge type	Effects
Social challenges	Social exclusion that can engender poverty
	Loss of confidence from consumers due to failure and difficulty in regaining same
	Less incentive for quality products in Least developed countries
	Questions as regards the openness of certification approach
	Level of commitment and involvement from stakeholders
Environmental and ethical challenges	Loss of equity and subsequently an unsustainable practice
	Divergent global perspectives and lack of support for indigenous technology
	Compliance may be evasive
Financial challenges	Huge costs of certification
	Small scale farmers lose access due to competitive disadvantage
	Inadvertent exclusion due to inability to obtain new markets

responsibility and environmental wellbeing by aquaculture is given in Table 1.9. The difficulty and high costs associated with data collection can be a serious setback in the process but with voluntary certification, there can be a huge database for environmental data that serve as indicators of the environmental sustainability of aquaculture (Lee 2009).

Table 1.9 Criteria for mitigating concerns of aquaculture in relation to its certification for sustainability

Concerns	Rationale	Criteria
Food safety	• Meet food safety regulations of the Codex Allimentarius • Be in line with all international food standards	• Use approved therapeutants, adhere to withdrawal periods • Use contaminant free feed with approved ingredients • Farm location is pollution free, suitable water quality free of microbial impact • Stock must be pathogen free • Traceability of inputs • HACCP hygiene conditions
Social welfare	• Equal market access for all producers • Worker's welfare	• Small holder, youth and gender inclusive post-certification market access • Involve all stakeholders with competing claims to resources • Adherence to labour and wage regulations • Clustering of small holder farmers for cost effective certification
Animal welfare	• Access to water and food, suitable environment, disease and injury control, functional improvement, behavioural/interactive freedom and mental and physical comfort	• Use international standards in aquatic health management • Quarantine must comply with FAO code of conduct for responsible fisheries • Consider specific pathogen free organisms • Stringent management of antibiotics and their discharge • Clean and hygienic culture environment for pathogen and parasite control • Limit harm to animals in production process with limited suffering at slaughter • Farm workers gain knowledge on animal welfare and health management

(continued)

Table 1.9 (continued)

Concerns	Rationale	Criteria
Environmental wellbeing	• Proper planning and determination of environmental impacts	• Adopt environmental impact assessment for site selection with support to manage impacts • Consider the environment in National aquaculture policy and plan • Inclusion of environmental quality and impact control in aquaculture governance • Water use with bias for conservation • Control fish escapes and import of exotics with restricted use of wild stocks in aquaculture • Censurable use of chemicals and drugs

1.7.3 Certification Schemes

Certification schemes are based on standards or codes of good practice that are documented by certifying organisations with the goal of sustainable aquaculture. These schemes are mostly species or region specific hence a thorough assessment and compliance requirements. However, the specific nature inhibits far-reaching acceptance and global coverage (Lee 2009).

According to Corsin et al. (2007), there are about 30 certification schemes in aquaculture with a bias for sustainability operating via different approaches. The number of schemes increased to a total of 40 schemes in 2009 (Global Trust Certification 2009). In Vietnam, Marschke and Wilkings (2014), reported that there are 4 certification schemes that have certified a total of 20 producers with certification still ongoing. The development of certification schemes is guided by the FAO (2011b) with guidelines for setting the standards, performing an accreditation and final certification.

Certification schemes can be categorized using several criteria. Lee (2009) used a classification scheme that divided the schemes as either organic or non-organic. Global Trust Certification (2009) also used a two category classification that includes trade and eco-friendly schemes while Corsin et al. (2007) adopted an eight category classification of the schemes using the advocate, trade and environment as anchors. We will attempt to also classify the schemes (Table 1.10) based on the two categories used by Lee (2009).

The scope of most of these certification schemes covers the environment but social welfare is excluded in organic schemes for aquaculture producers in developed nations (Lee 2009). The safe quality food (SQF) standard focuses entirely on food safety and traceability. Each scheme has advocates that prepare the standards and present the same to target producers with credibility being either inherent for state-owned agencies or derived from third party auditors especially for non-organic

Table 1.10 Aquaculture certification schemes

Scheme	Promoter	Coverage	Labelling	Species	Website
Non-organic					
Best Aquaculture Practice	Global Aquaculture Alliance	Global	Eco-label	Shrimp, tilapia, pangasius, salmon channel catfish	www.gaalliance.org www.aquaculturecertification.org
SEASAIP	Asia Seafood Improvement Collaborative	Asia	Seafood watch yellow	Shrimps: *Litopenaeus. vannamei* and *Penaeus monodon*	www.asicollaborative.org
Global GAP	Global GAP	Global	GGN	Pangasius, salmon, penaeid shrimp	www.globalgap.org
Aquaculture Stewardship Council	World Wildlife Fund	Global	Farmed responsibly	Currently 12 species, but envisages covering all major species	www.asc-aqua.org
Friend of the Sea	NGO: Friend of the Sea	Global	Eco-label	Multi-species (Salmon, seabass, shrimps etc.)	www.friendofthesea.org
Thai Quality Shrimp	Thai Dept. of Fisheries	National	Eco-label	Penaeid shrimp and Freshwater prawn	www.thaiqualityshrimp.com
ISO 9001 and ISO 14001	NGO: International Standards Organisation	Global	Quality	All species	www.iso.org
SQF Code 7	Safe Quality Food Institute	Global	Food safety	All species	www.sqfi.com www.fmi.org
Carrefour Filiere Qualite	Carrefour	Global	Eco-label	Oyster, shrimp, salmon	www.carrefour.com
Label Rouge	French Ministry of Agriculture	France, Madagascar, Scotland	Eco-label	Salmon, penaeid shrimp, seabass, oysters turbot	www.label-rouge.org
Malaysian Aquaculture Farm Certification	Malaysian Government	National	Nil	Penaeid and freshwater shrimp, fish, molluscs and ornamental fish	http://www.dof.gov.my/

(continued)

Table 1.10 (continued)

Scheme	Promoter	Coverage	Labelling	Species	Website
Scottish Salmon Producers' Organisation code of good conduct	Scottish Salmon Producers	National	COGP	Salmon	www.scottishsalmon.co.uk
SIGES-Salmon Chile	Fundacion Chile/CBPA	National	Nil	Salmon	www.salmonchile.cl/en
Organic					
Bioland	Bioland eV	Germany	Eco-label	Freshwater fish	www.bioland.de
International Federation of Organic Agriculture Movements	IFOAM Organics International	Global	Eco-label	Seaweeds, bivalves, etc.	www.ifoam.org
Bio-gro	New Zealand Biological Producers and Consumers Society	New Zealand	Eco-label	Fish, shellfish, crustaceans	www.biogro.co.nz
Bio-Suisse	NGO: Federation of Swiss organic farmers	Switzerland	Eco-label	Carp, char, trout, perch	www.bio-suisse.ch
Naturland	NGO	Global	Eco-label	Salmon, milkfish, penaeid shrimp, mussels, arapaima	www.naturland.org
Organic Food Federation	NGO	EU	Eco-label	Cod, salmon	www.orgfoodfed.com

schemes. Organic schemes must conform to guidelines specified by organic farming promoting organisations such as IFOAM (Germany), IMO (Switzerland), ACO (Australia) and a host of others. It is often a challenge for organic aquaculture certifying bodies to ensure that the recommended farm practices adhere well to the product requirements and to the rearing conditions for a particular species such that the farm outputs and market demands are reasonably balanced (Nair et al. 2014). The organic certifying bodies are audited to ensure that standards are met.

Two generic quality management standards that can be employed by any organisation are the ISO 9001 and ISO 14001 standards. Internal quality management in aquaculture firms as well as aquaculture product processing firms can be achieved by applying the ISO 9001 quality management standard, while environmental management can be made to conform with acceptable standards by the use of ISO 14001 management standards. In terms of specifics, the SQF code 7 covers aspects of food and feed safety in the aquaculture processing and production industry. The Aquaculture Certification Council (ACC) of the Global Aquaculture Alliance (GAA) seeks to promote Best Aquaculture Practices (BAP) for responsible aquaculture covering animal welfare, social and environmental wellbeing, food safety and traceability. The ACC standards target specific aquaculture species and include steps for risk analysis using guidelines embedded in the standards, and hence are more relevant to the aquaculture industry compared to the generic ISO 9001 and 14001 that both demand self-risk assessment from the farmer.

Another key international certification scheme is the GlobalG.A.P. (Global Good Agricultural Practice). GlobalGAP does not use eco-labelling but instead is a business to business certification scheme. It also covers food safety, social and environmental wellbeing, animal welfare and wellbeing of the workforce. Guidelines cover all areas of the production process from spawning through stocking to harvesting and processing.

Aquaculture dialogues have been initiated by the World Wildlife Fund (WWF) and management of the standards developed was transferred to the Aquaculture Stewardship Council (ASC). A total of 8 aquaculture standards that cover 12 aquaculture species have been developed. The ASC seeks to use efficient markets to reduce negative impact of aquaculture production considering social and environmental wellbeing through standards and compliance.

The seafood retail chain has also taken the responsibility of ensuring sustainable production seriously with the promotion of their own eco-labels and standards. These are embedded in internal business chain guidelines, ethics and codes of practice. The UK's Tesco adopts guidelines for sustainable fish products using the FAO Code of Conduct for Responsible Fisheries while sustainable aquaculture of salmon is being advocated by the development of standards for salmon products on offer by the giant retail outlet. Sainsbury's in the UK favours the use of Global GAP and organically certified farmed fish for its cultured fish supplies (Global Trust Certification 2009). In North America, the Food Market Institute (FMI) has engaged experts and franchises to develop proactive sustainable seafood standards with representation from Canada's Loblaw and Sobeys supply chains. Carrefour group in France has developed its own standards for the farmed fish that it sources, considering minimal environmental damage from their production hence a bias for tilapia, pangasius and other species with limited need for fishmeal based diets. The French Label Rouge is also used to certify quality of some aquaculture products including oysters, seabass, Scottish salmon and shrimp imported from Madagascar.

National certification schemes also exist in several countries in the south. In Thailand, there is the Thai Quality Shrimp certification scheme. Other schemes with national focus include the Vietnamese GAP, Hong Kong's Accredited Fish Farm Scheme, Chilean Code of Good Environmental Practices for salmon, and the Malaysian Aquaculture Farm Certification scheme.

1.8 Concluding Remarks

Aquaculture is a rapidly growing food production sector with level of intensification and number of people involved in the industry also increasing. In the wake of its expansion, there has been negligence on the part of operators that created environmental and ecological problems. Aquaculture can be a threat to genetic diversity, water quality, general ecology, health and natural resources. This notwithstanding, the environment can also impact negatively on aquaculture.

Sustainable aquaculture holds the key to mitigating the threats posed by aquaculture while also ensuring that this important food producing sector remains very productive. Several approaches must be used in order to ensure that aquaculture does not impact negatively on the environment. The determination of suitable sites with capacity to absorb the biomass from aquaculture as well as waste is the first step that needs to be taken to achieve the goal of sustainability. Site selection and carrying capacity estimation must follow each step of aquaculture from planning to actual culture, and it must be an ongoing process. In assessing sites for aquaculture, it is important to also understand the risks involved in operating aquaculture facilities in an area considering the introduction and transfer of pathogens and other risks. Risk assessment in aquaculture must be carried out in conjunction with local and indigenous communities so that knowledge of the area is built into the process. The use of stakeholder opinion is a bone of contention for the scientific community. However, the knowledge from community members can be very useful. Sustainable aquaculture can also be achieved with the use of the ecosystem approach to aquaculture when regulatory agencies are planning for aquaculture. This approach has scientific depth because it relies on modelling and seeks to ensure sustainable aquaculture through management, improvement of livelihoods as well as consideration of other resource users.

Furthermore, effective regulation of aquaculture through governance is expected to assist the enforcement of the ecosystem approach to aquaculture. The application of governance without corrupt practices will ensure good product quality, sound environmental management and general social wellbeing. Gender sensitivity is also crucial in governance hence gender representation and responsiveness are two key factors that must be considered in the process of governance. The emergence of aquaculture certification and standards has created room for operators to ensure they remain competitive in the market given the consumer demand for products that are produced sustainably and are safe for consumption. Transparency, integrity and accountability are the key drivers of certification. Certification of small scale aquaculture facilities is affected by social, environmental/ethical and financial challenges. Certification schemes are quite numerous with each scheme presenting unique standards that are used as reference in auditing aquaculture ventures. These standards can be categorized using several criteria. However, two basic categories included are the organic and non-organic standards.

Conclusively, since aquaculture can have adverse effects on the environment, it is highly desirable to understand and predict these impacts so that remedial actions can be taken to keep these consequences in check and within allowable thresholds. Continuous monitoring of aquaculture sites and zones by regulators is also important since it will lead to appropriate interventions when they are needed so as to foster environmental wellbeing, ecological integrity, desirable food quality attributes, and social security.

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