production of these feed ingredients. Aquaculture products grown on non-traditional feedstuffs should also be assessed for acceptable sensory characteristics such as odor, color, taste, and texture. Traceability, effect on human health, and impact on the environment are significant issues to be addressed in the use of non-traditional ingredients. Databases are available on feed ingredients that include their nutrition composition, usage in industrially- and farm-made aquafeeds, quality criteria, limitation of use, as well as documented feeding studies (Tacon *et al*., 2009; Hertrampf and Pascual, 2000). Databases should be updated to contain the current information on feed ingredient including those on non-traditional feed ingredients, and should be made available to feed manufacturers, researchers, fish farmers, policy makers, and other stakeholders.

The use of alternative substitutes for FM and FPs has some setbacks such as poor palatability, poor digestibility, essential amino acids deficiency, high fiber content, and limited inclusion level. Technological innovations are therefore needed to effectively use these in aquafeeds. Genetic engineering can improve amino acid profile in legumes and increase DHA/EPA levels of plant-derived oils. In addition, with technological innovations, concentrated and hydrolyzed protein products can be made cheaper and bone content in meat and bone meal can be adjusted to reduce calcium levels. In addition, genetic selection can be done for strains/stocks that can efficiently utilize plant derived non-traditional ingredients. It is apparent that the demand for aquafeed will continue to increase in the region as more aquaculture operations will be producing fish through fed aquaculture. The development of efficient aquafeeds with less dependence on FM and FPs should be pursued aggressively and with more multidisciplinary research efforts. Some feed ingredients with potentials for use as substitutes for these resources are already found in the market. Their efficacy to substitute FM and FPs in aquafeed including those of non-traditional feed ingredients can be increased through technological innovations.

5.5 Minimizing Impacts of Aquaculture on the Environment

Aquaculture is the fastest-growing food production system globally, with about 9% increase in production per year since 1985 (Diana, 2009). On the average, Asia which is known as the birthplace of aquaculture (Tacon *et al*., 1995) provides 83% (range: 59-91%) of the total world aquaculture production, 14% of which comes from Southeast Asia (**Fig. 38**). Indonesia and the Philippines contribute the most to aquaculture production in Southeast Asia at 23-42% and 20-45% of the total production from aquaculture, respectively (**Fig. 39**). With the increasing demand for fish and fishery products coupled with the dwindling supply of wild aquatic resources, aquaculture has been projected to compensate the declining fishery production and considered a reliable solution to food security problems. However, as aquaculture production intensifies, a lot of problems have been linked with it.

The phenomenal growth of aquaculture in the recent years has caused modification, destruction or complete loss of habitat; unregulated collection of wild broodstocks and seeds; translocation or introduction of exotic species; loss of biodiversity; introduction of antibiotics and chemicals to the environment; discharge of aquaculture wastewater, thus coastal pollution; salinization of soil and water; and dependence on fishmeal and fish oil as aquaculture feed ingredients, to name a few (Chua *et al*., 1989; Iwama 1991; Beveridge *et al*., 1994; Naylor *et al*., 2000; Primavera, 2006). Efforts have been done by the countries in the region to increase production and at the same time minimize impacts of aquaculture on the environment.

5.5.1 *Status, Issues and Concerns*

The many advantages of aquaculture provide a strong and credible argument for its continued implementation. Aquaculture continues to provide valuable food supply and economic support for many countries. However, the industry has its own share of problems that need to be addressed, the most important of which is its impact on the environment. In order to limit the potential negative

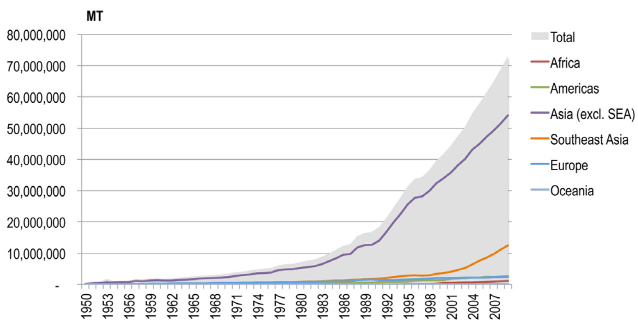

Figure 38. Aquaculture production from 1950 to 2009
*(**Source:** FAO database)*

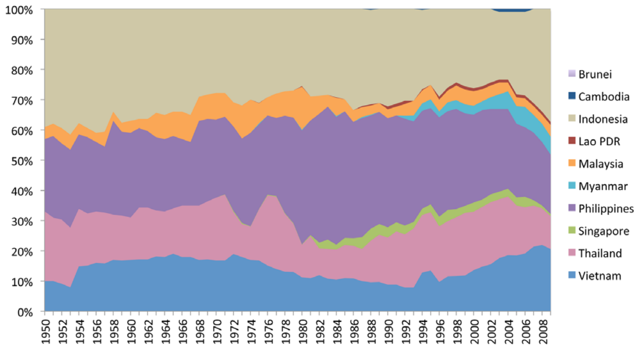

Figure 39. Contribution (%) of Southeast Asian countries to aquaculture production of the region from 1950 to 2009
*(**Source:** FAO database)*

environmental impacts of aquaculture effluents, studies are being conducted, policies and laws are being formulated, and there is a concerted effort of the scientific community, academe, policy makers, farm owners, and government authorities to come up with approaches that could help reduce production of aquaculture wastes or mitigate its impact.

The specific strategy for mitigating the negative effects of aquaculture will depend on local conditions. Among the basic approaches are choosing a location with high flushing rates and deep water, and using dry, easily digested feeds that will help reduce the potential negative impacts (Iwama, 1991). In addition, treating farm effluents prior to discharge; limiting the concentration of specific dissolved/ suspended inorganic/organic materials and/or nutrients contained within the effluent discharged from the farm; establishing maximum permissible amounts of specific nutrients (such as total nitrogen or phosphorus) that the farm is able to discharge over a fixed time period; limiting the total number of licenses that can be issued and/or size of farm, depending upon the vicinity of other farming operations and the assimilative environmental carrying capacity of the receiving aquatic ecosystem; limiting or fixing the total quantity of feed the farm is able to use over a fixed time period; fixing maximum permissible specific nutrient levels within the compound feeds to be used to rear the species in question; banning the use of specific potentially high-risk feed items such as fresh/ trash fish and invertebrates; banning the use of certain chemicals and antibiotics; prescribing minimum feed performance criteria; requiring the use of specific Codes of Conduct, including appropriate Best Management Practices (BMPs) for farm operations; requiring the development of suitable farm/pond sediment management strategies for the storage and disposal of sediments; and/ or requiring the implementation of an environmental monitoring program have been suggested by Tacon and Forster (2003). However, most fish farmers still do not follow these approaches at present, and thus, continuing implementation of only some but not most, would mean that the environment continues to suffer.

Coastal aquaculture is a traditional practice in Southeast Asia, and prior to the establishment of SEAFDEC/ AQD in 1973, Indonesia has been the top aquaculture producing country in the region (**Fig 40**). Five years after SEAFDEC/AQD was established until 2004, Philippines led the Southeast Asian countries in terms of aquaculture production. However, as aquaculture development in the region accelerated, it has created negative environmental impacts. As one of the leading institutions for aquaculture research and development in Southeast Asia, SEAFDEC/ AQD needs to continue developing management measures to mitigate deteriorating coastal water quality and the adverse environmental impacts of aquaculture development, important issues that have become a matter of urgency to the Southeast Asian region.

Among the coastal ecosystems, mangroves are the most greatly affected by aquaculture. The positive feedback of aquaculture in boosting production and compensating losses from capture fisheries is usually coupled with negative feedback of converting mangroves to aquaculture ponds. Southeast Asia used to have the widest and the most diverse mangroves in the world but between 1980 and 2005 it suffered a decline of more than 26% (Spalding *et al*., 2010), where most of the losses were due to conversion of mangrove areas into milkfish and shrimp ponds (Naylor *et al*., 2000). Looking at the countries as major contributors to aquaculture production in Southeast Asia, Indonesia which had the widest mangrove cover worldwide (Giri *et al*., 2010; Spalding *et al*., 2010), began large-scale mangrove conversions for extensive milkfish ponds called tambaks, as early as the 1950's (Fast and Menasveta, 2003). The country reportedly converted 269,000 ha of mangroves to shrimp ponds between 1960 and 1990 (Harrison and Pearce, 2000 in Thornton *et al*., 2003) and which remains a major threat to its mangroves (Spalding *et al*., 1997).

From 1951 to 1988, almost half of the 279,000 ha of Philippine mangroves were developed into culture ponds with 95% of brackishwater ponds in 1952–1987 derived from mangroves (Primavera, 2000). From 1975 to 1993, the mangrove area in Thailand was halved from 312,700 to 168,683 ha. Mangrove conversion for shrimp aquaculture began in 1974 but accelerated in 1985 when shrimp farm areas expanded from 31,906 to 66,027 ha and number of farms increased from 3,779 to 21,917 in 1983-1996 (Barbier, 2003). Vietnam has reportedly lost more than 80% of its mangrove forests over the last 50 years and shrimp aquaculture is considered to be the greatest threat to the remaining mangroves (Thornton *et al*., 2003). These conversions result in loss of goods and ecosystem services generated by mangroves including plant and wood products, provision of nursery habitat, coastal protection,

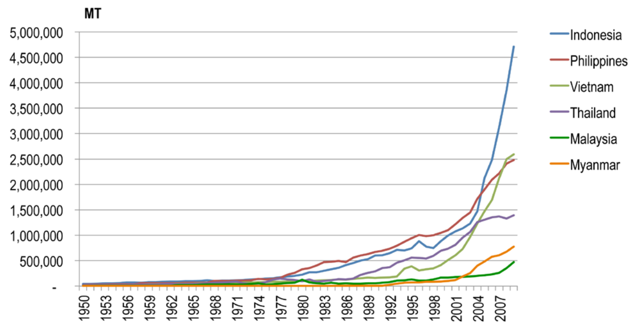

Figure 40. Aquaculture production of the top six producing countries in Southeast Asia from 1950 to 2009
*(**Source:** FAO database)*

flood control, sediment trapping and water treatment (Macnae, 1968; Bandaranayake, 1998; Ewel *et al*., 1998). In Southeast Asia, mangrove-dependent species account for roughly one-third of yearly wild fish landings excluding trash fish (Naylor *et al*., 2000). A positive relationship between fish and shrimp landings and mangrove area has been documented in Indonesia (Martosubroto and Naamin, 1977), Philippines (Camacho and Bagarinao, 1986) and Thailand (Barbier, 2003). Aside from losing these goods and services, converting mangroves into aquaculture ponds transforms an open access fisheries with multiple users to a privatized farm resource of few wealthy individual investors and business enterprises.

The impacts of aquaculture on biodiversity are rarely positive, sometimes neutral, but usually negative to certain degree (Beveridge *et al*., 1994). Loss of biodiversity is one of the consequences of habitat modification or its complete destruction to give way to aquaculture ponds. Globally, mangrove biodiversity is highest in the Indo-Malay Philippine Archipelago with 36-46 of the 70 known mangrove species occurring in this region. However, the region has one of the highest rates of mangrove area loss at an estimated of 30% reduction in mangrove area since 1980 (Polidoro *et al*., 2010). Although mangrove species diversity may be low, faunal, microbial and other associated species diversity can be high (Alongi, 2009). Thus, losing mangroves means losing a highly complex system that serves as nursery or permanent residence for a range of organisms, both from the terrestrial and the aquatic environments (Macnae, 1968; Alongi, 2002). The interdependence of mangroves with sea grass beds and coral reefs is apparent in the movement of fish and other organisms observed between these three adjacent systems (Gillanders *et al*., 2003; Sheridan and Hays, 2003). Losing one of these habitats will affect all three ecosystems and everything that dwells in them. Aside from habitat modification, unregulated collection of broodstock and wild seeds for use in aquaculture facilities may eventually threaten the wild population. The same could also happen to fish species harvested for use in fishmeal and fish oil production. Regardless of purpose, indiscriminate harvesting of wild stocks has negative impact on biodiversity.

As the world's fastest growing agriculture industry, aquaculture has heightened public concerns about pollution, water quality degradation, health and other violations of the public trust (Costa-Pierce, 1996). Aquaculture wastewater outputs and loads vary widely, depending upon the species cultured, farming systems employed and aquatic environment utilized (Tacon and Forster, 2003). Aquaculture wastes are mostly derived from excess feeds and fecal matter, and continuous discharge of wastewater without treatment could result in a chain of undesirable events, that include serious oxygen deficit caused by the decomposition of organic substances; sedimentation; eutrophication or algal bloom caused by the accumulation of organic nutrients like nitrogen and phosphorus; changes in energy and nutrient fluxes, changes in pelagic and benthic biomass and community structure and fish stocks; low productivity; and sometimes disease outbreak. Moreover, inadequate handling of wastewater has serious consequences for human health, the environment and economic development (Cao *et al*., 2007). This past decade, fish kills have been a recurring phenomenon in the Philippines. The most serious among the recent ones was in Taal Lake, Batangas last 28 May 2011 which resulted in the death of about 752.6 MT of fish with an estimated value of US$1.3 million. Fish kills in the country have been attributed to eutrophic waters and algal bloom (Azanza *et al*., 2005; San Diego-McGlone *et al*., 2008) which could be linked to uncontrolled proliferation of fish pens and cages to more than double the allowable limit (Yap *et al*., 2004; San Diego-McGlone *et al*., 2008).

Aside from wastes, aquaculture also introduces various chemicals to the environment in the form of therapeutants, disinfectants, water or soil treatment compounds, algicides and pesticides, fertilizers, and feed additives. The excessive use of these chemicals can result in toxicity to non-target populations, human consumers and wild biota, and the accumulation of their residues (Primavera, 2006). Antibiotics such as tetracycline, oxytetracycline, oxolinic acid, furazolidone, and chloramphenicol have also been used excessively the result of which could lead to the development of bacteria-resistant populations (Tendencia and de la Peña, 2001; Hoa *et al*., 2011).

5.5.2 Challenges and Future Direction

There is an urgent need to change the present aquaculture practices in order to minimize its environmental impact and preserve the remaining habitats which may eventually be affected as aquaculture continues to intensify. Aquaculture had intensified because of diminishing wild stocks, but there are other ways of replenishing depleted stocks, such as regulating the fishing effort; restoring degraded nursery and spawning habitats; or enhancing the stocks (Blankenship and Leber, 1995).

In the case of aquaculture, habitat rehabilitation or restoration should be more focused on mangroves which suffered most because of pond construction. The review paper of Ellison (2000) suggested that although most of the objectives of restoration projects were for forest products, coastal protection and stabilization, two Southeast Asian countries have set their goals for maintenance or sustainability of fisheries (Malaysia) and provision of habitat for wildlife (Vietnam). Rehabilitating nursery habitats is effective in restoring populations of naturally occurring species and considered as one of the approaches in enhancing fisheries (Welcomme and Bartley, 1998). This has been observed in mud crabs, *Scylla* spp. in the reforested mangroves in Kalibo, Aklan in the Philippines (Walton *et al*., 2007) and mangrove recolonized abandoned pond in Dumangas, Iloilo also in the Philippines (Lebata-Ramos, unpublished data).

Stock enhancement using individuals reared in aquaculture facilities is becoming a popular method of supplementing depleted stocks (Bert *et al*., 2003). Bell *et al*. (2006) discussed two of the most successful stock enhancement initiatives, which are the augmentation of scallop fishery in Hokkaido, Japan causing a four-fold increase in annual harvests; and the 20-year shrimp release program in China which achieved a 7 to 10-fold return of investment. The success in stock enhancement depends on setting the management goals and identifying the right species for release. Once these are determined the ten essential components of a "responsible" enhancement program suggested by Blankenship and Leber (1995) can be distilled into three critical issues, namely: 1) understanding the nature of the system or the habitat for release; 2) producing robust, compatible individuals for release; and 3) evaluating the effects of releases (Blaylock *et al*., 2000).

Most stock enhancement activities have failed because of lack of proper habitat for released juveniles. Stock enhancement can be very effective if accompanied with habitat restoration because it will be of no effect in situations where recruitment is limited by the lack of sufficient nursery areas (Bell *et al*., 2006). Although stock enhancement activity may change the status quo of the ecosystem, given the substantial damage these ecosystems have suffered due to anthropogenic activities and the depletion of fisheries resources due to overfishing, the impact of adding juveniles which is aimed at improving production of the target species should not be a cause of great concern, provided that this activity is conducted responsibly and that this will not cause further degradation to the ecosystem and its diversity (Lebata, 2006). Contrary to most beliefs, mangroves and aquaculture are not necessarily incompatible (Primavera, 2006). Marginal coastal sites such as denuded and over-exploited mangrove areas and unproductive or abandoned fishponds can be made productive and economically profitable through aquasilviculture, the integration of aquaculture with silviculture or the harmonious co-existence of aquaculture species and mangrove trees (de la Cruz, 1995).

This mangrove-friendly aquaculture technology had been applied in shrimp ponds (Primavera *et al*., 2007) and mud crab pen culture (Triño and Rodriguez, 2002; Primavera *et al*., 2010) in the Philippines; mariculture in Taiwan (Su *et al*., 2011); shrimp-mangrove farms in Vietnam (Binh *et al*., 1997); and milkfish pond culture, milkfish and shrimp polyculture (Fitzgerald and Savitri, 2002), and shrimp pond culture (Shimoda *et al*., 2006) in Indonesia. A forestry program was initiated in Indonesia by the state forest enterprise in 1976 integrating forest management with fish production. Popularly known as the 'tumpang sari', the program allows for crops to be grown while protecting the forest and optimizing land use, filling 80% of the ponds with trees and leaving 20% for fish production (Adger and Luttrell, 2000). Aside from integrating aquaculture into the mangroves, culture species, *i.e.* seaweeds, mussels and oysters, and fish can also be reared in mangrove waterways.

The concept and practice of integrated aquaculture is well-known in inland environments in Asia, but much less reported in the marine environments. In the recent years, the idea of integrated aquaculture has been often considered a mitigation approach against the excess nutrients/organic matter generated by intensive aquaculture activities particularly in marine waters. Integrated marine aquaculture can cover a diverse range of co-culture/farming practices, including the integrated multitrophic aquaculture (IMTA) and aquasilviculture. IMTA explicitly incorporates species from different trophic positions or nutritional levels in the same system for bioremediation and economic returns (Soto, 2009). Integration can be directly beneficial to farmers either through additional valuable products, improved water quality, prevention of diseases, habitat conservation, or increased allowable production volumes through waste reduction (Troell, 2009). Neori *et al*. (2004), for example, reported that annually, a 1-ha land-based integrated sea bream–shellfish–seaweed farm can produce 25 MT of fish, 50 MT of bivalves and 30 MT fresh weight of seaweeds or 55 MT of sea bream or 92 MT of salmon, with 385 or 500 fresh weight of seaweeds, respectively, without pollution. Modern integrated systems are bound to play a major role in the sustainable expansion of world aquaculture. IMTA seems to be the direction of aquaculture which appears to be economically and environmentally sustainable.

Most aquaculture wastes are usually dietary in origin. Aquaculture feeds and feeding regimes can play a major role in determining the quality and potential environmental impacts of fish and crustacean farm effluents (Tacon and Forster, 2003). Optimized local feed management together with further development of fish feed in terms of increased digestibility of feed components will lead to greater profitability to the farmers and also minimize aquaculture wastes (Kolsäter, 1995). Among the best management practices (BMPs) related to feeding management, Boyd (2003) suggested that fertilizers should be used only as needed especially to maintain phytoplankton blooms. Moreover, it is also important to use high quality and water stable feeds that contain only the required amount of nitrogen and phosphorus than necessary; and apply feeds conservatively to avoid overfeeding and to assure that as much of the feed is consumed as possible. Feeding may be also improved through the use of automatic feeder and by employing compensatory feeding. An experiment involving three automated feeding systems gave FCRs of 0.94, 0.93, and 1.05, providing good control of feeding and helping in the improvement of feeding efficiency (Myrseth, 2000).

In a feeding experiment on *Pangasius bocourti*, there was no significant difference in the final weight among the five groups tested indicating complete compensation in the fish experiencing restricted feeding. Improved feed conversion efficiency was experienced in the juveniles of *P. bocourti* when restricted feeding was conducted (Jiwyam, 2010). Atlantic halibut reared on a repeated 5/10 week starvation/re-fed regime for 3 years led to full growth compensation, higher feed conversion efficiency, lower male maturation, and improved flesh quality (Foss *et al*., 2009). In one of the compensatory feeding experiments conducted by SEAFDEC/AQD, biomass of milkfish reared in brackishwater ponds and fed every other day was comparable to stocks fed daily resulting to one-half of the usual FCR and 50% savings on feed inputs (de Jesus-Ayson, unpublished data). Based on these results, feeding regimes may be manipulated in such a way that feed inputs to the environment may be minimized without sacrificing production.

Aquaculture may be the ultimate solution to the problem of dwindling fishery production. Since most of the time, aquaculture does nothing good to the environment, and in order to compensate the diminishing fishery production and meet the demands of fishery products for the human population which continue to grow, aquaculture must be redesigned to minimize its impact on the environment and make it more environmentally and at the same time economically sustainable. Scientific studies on how aquaculture has destroyed habitats, polluted the waters, threatened non-target species, and a long list of other impacts; and how aquaculture should be done to make it sustainable and environment friendly are readily accessible. However, despite the easy access to such information, aquaculture continues to pollute the environment. Therefore, scientific findings should be properly and widely disseminated to fish farmers, hatchery operators, feed suppliers, policy makers, and government agencies to make them understand that protecting the environment is not the task of just one person but should be a joint effort of everyone producing from it, using it, and living in it. Science should be strongly supported by policies that are strictly implemented and enforced in order to achieve the goal of having a better and cleaner environment in the future.

6. ADAPTATION AND MITIGATION OF THE IMPACTS OF CLIMATE CHANGE

Capture fisheries and aquaculture are the most beneficial livelihood sources in coastal communities. However, the sustainability of these sources is being subjected to various threats and pressures especially during the past decades. In the advent of these serious fisheries and aquaculture concerns coupled with environmental changes, the people's dependence on fisheries in the Southeast Asian region for economic growth is in question. Considering that nowadays, extreme meteorological events have increasingly occurred with frequent and more severe manifestations. Therefore, it is valid to analyze how people involved in fisheries react and adapt to existing climate fluctuations (Daw *et al*., 2009). It is noteworthy that climate change affects fisheries and aquaculture directly by influencing the fish stock and the global supply of fish consumption, or indirectly by influencing fish prices or the cost of goods and services required by fishers and fish farmers (WFC, 2007).

In particular, strategies and interventions to mitigate the effects of climate change to the fisheries industry should be established. In aquaculture for example, the impacts of climate change to the various culture, and its effect to the cultured species and their vulnerability to the environmental changes as well as to the wild stocks targeted by capture fisheries, should be assessed. Environment friendly strategies to lessen the sectors' impacts to the environment should also be developed, which also pertains to the efforts to reduce the carbon footprint of fisheries. These efforts should be taken with serious consideration considering that many peoples in the Southeast Asian region are increasingly dependent on the fishery resources as evidenced in the per capita consumption that reached a new all time high (FAO, 2010a).

Since these resources come mostly from our vulnerable coastal areas, it is therefore important and urgent to integrate fisheries management in resource exploitation with the objective of ensuring sustainable utilization of the very important resources, protecting vulnerable areas and species, and eventually mitigating the effects and ensuring the stakeholders' adaptation to climate change.

6.1 Vulnerability of Coastal Habitats

It is most certain and widely recognized that the effects of climate change are (but not limited to) sea-level rise, seasonal monsoon/rainfall variations, increased and stronger incidence of storms and typhoons, increased land-based run-offs, and sea-surface temperature (SST) rise. These effects highly influence the productivity of the coastal habitats where most of the fishery resources are