# FISH for the PEOPLE

A Special Publication for the Promotion of Sustainable Fisheries for Food Security in the ASEAN Region
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## **Boosting Cooperation**
## in Sustainable Fisheries Development through Collective Collaboration

SEAFDEC Southeast Asian Fisheries Development Center

*Editor in Chief (Fish for the People)*

*SEAFDEC Secretariat*
*Kasetsart University Campus*
*P.O. Box 1046, Kasetsart Post Office,*
*Bangkok 10903, THAILAND*
*E-mail: fish@seafdec.org*




# Editorial

As defined by many scholars, cooperation is a voluntary arrangement among two or more entities to perform together (*co-operate*) towards a mutually beneficial goal. In collaboration on the other hand, the entities work together (*co-labor*) through cooperative arrangement to achieve a single shared goal and agree to achieve such common goal. Therefore, to cooperate is to work with someone to do something while to collaborate implies working alongside with someone to achieve that something.

In sustainable fisheries development, cooperation among the stakeholders could be enhanced through the collective process of collaboration. The famous quotation of John Donne: "***No man is an island***" is very fitting for the fisheries sector because not one fisher-stakeholder could be self-sufficient without relying on one another for survival. As humans, fisher-stakeholders need to interact with consumers, for without the consumers and market, fishers' fish and fishery products could go to waste depriving them of their incomes. In organizations, interaction with others within and outside an organization is imperative because working alone could exhaust and weaken one's available resources hindering the ability to achieve a desired goal, as demonstrated in another saying which goes "***alone very little could be done but together much could be achieved***".

Adhering to the above quotation and saying, the Southeast Asian Fisheries Development Center (SEAFDEC) collaborates with concerned agencies and organizations to speed up the sustainable development of Southeast Asian fisheries. In the midst of the fast changing world of development, SEAFDEC has been receiving accolades in sustainable fisheries development which it had accomplished in much shorter time because of its efforts in establishing collaboration and cooperation with various concerned agencies, notwithstanding the need to safeguard its human and financial resources.

In accordance with the "**Agreement Establishing the Southeast Asian Fisheries Development Center"** or the **Agreement**, SEAFDEC is entrusted to promote sustainable fisheries development in Southeast Asia through mutual cooperation among the Member


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Governments of SEAFDEC and collaboration with international organizations and other agencies. Thus, SEAFDEC has been cooperating with the ASEAN by serving as its technical arm in fisheries development through the ASEAN-SEAFDEC Strategic Partnership (ASSP). Under the ASSP mechanism, the Fisheries Consultative Group established in 1998 has been strengthened for the sustained implementation of fisheries and aquaculture programs in the ASEAN Member States (AMSs) with funding support from the Japanese Trust Fund of the Fisheries Agency of Japan (FAJ). While collaborating with the FAJ and its various agencies (*e.g.* the Fisheries Research Agency), SEAFDEC avails of the much needed resources including expertise in fisheries advancements that facilitate the implementation of activities that are beneficial to the AMSs. In a related development, the collaborative partnership with Sweden for example, enables SEAFDEC to promote sub-regional cooperation among the Member Countries, ensuring that issues on the well-being of transboundary waters of concerned Member Countries are addressed at a much faster rate.

The SEAFDEC Departments, on their parts, also collaborate with respective national agencies and other organizations, making the development, verification and transfer of technologies timely, affordable and reachable by all stakeholders. Collaboration boosted with cooperation is therefore the basic principle being promoted within SEAFDEC, not only because of the **Agreement** but also of the principle that all works in fisheries cannot be done by SEAFDEC alone but through a united effort of the many concerned champions of sustainable fisheries development.

Furthermore, while a "borderless" economic community is being established within the ASEAN, it is the goal of SEAFDEC to contribute to speeding up such integration by narrowing the gap of the ASEAN countries in terms of fisheries development while maintaining the specificity of the region's fisheries sector. Therefore, collaborating and cooperating with countries and agencies concerned with fisheries development is the route that SEAFDEC is committed to take up in order to achieve such goal.

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FISH for the PEOPLE is a special publication produced by the Southeast Asian Fisheries Development Center (SEAFDEC) to promote sustainable fisheries for food security in the ASEAN region.

# **New Challenges for Scientific and Technical Cooperation in Fisheries R&D:** the SEAFDEC-FRA Partnership

*Virgilia T. Sulit* and *Nualanong Tongdee*

The Southeast Asian Fisheries Development Center (SEAFDEC) and the Fisheries Research Agency (FRA) of Japan have had a long history of partnership in the development of sustainable fisheries in the Southeast Asian region. After its establishment in 1967, SEAFDEC charted a linkage with the National Fisheries Research Institute (NFRI) of Japan for the formulation of R&D programs in fisheries for Southeast Asia, paving the way for the development of sustainable fisheries programs for the region. When the original centers of NFRI were drawn up into an independent body in 2001, henceforth known as the Fisheries Research Agency (FRA) of Japan, SEAFDEC re-activated and formalized its collaboration with FRA. Since then, several collaborative activities in fisheries development had been undertaken in the Southeast Asian region under the said partnership. However, it was not until 2004 that the formal five-year arrangement was signed between FRA and SEAFDEC, and five years later in 2009, the said collaboration was extended for another five years until 2014 marking a ten-year strong and sustained history of collaboration between SEAFDEC and FRA.

As soon as the initiated 10-year cooperation between SEAFDEC and FRA ended on 21 January 2014, the renewed Memorandum of Understanding (MOU) for Scientific and Technical Cooperation during 2014-2019 was signed on 23 January 2014 by the President of FRA, Dr. *Toshihiko Matsusato* on behalf of FRA and by SEAFDEC Secretary-General, *Dr. Chumnarn Pongsri* for SEAFDEC. The renewed MOU extends the technical and scientific cooperation between the two parties in order to strengthen the development of sustainable fisheries and aquaculture in the ASEAN countries through the programs and activities of SEAFDEC.

The Fisheries Research Agency (FRA) is among the first and original collaborating partners of SEAFDEC for the sustainable development of fisheries in the Southeast Asian region. With headquarters in Yokohama City, Japan (**Fig. 1**), FRA comprises ten research institutes and centers (Matsusato, 2014a), six (6) of which are regional institutes and four (4) specific field institutes/centers that are most relevant to the SEAFDEC-FRA collaboration, *i.e.* National Research Institute of Far Sea Fisheries (Shizouka Prefecture), National Research Institute of Aquaculture (Mie Prefecture), National Institute of Fisheries Engineering (Ibaraki Prefecture), and Marine Fisheries Research and Development Center (Kanagawa Prefecture). From results of the research activities conducted at these institutes and centers, FRA published enormous quantity of technical and scientific papers. In a study conducted by Thomson-Reuters on scientific outputs, FRA ranked as the No. 1 agency with the most number of scientific papers in fisheries for the past 15 consecutive years from 1997 to 2011 (Matsusato, 2014a).


**Fig. 1.** Headquarters and research institutes/ centers of FRA in Japan (Adopted from Matsusato, 2014a)

## The SEAFDEC-FRA Collaboration

Under the SEAFDEC-FRA collaboration, FRA provides technical assistance focusing on capacity building for SEAFDEC and the Southeast Asian countries, *i.e.* through research studies on special topics; improved information collection; publications; consultations including workshops, symposia, meetings; lectures on relevant emerging topics; awareness building; and training (**Box 1**). In terms of expertise, FRA dispatched 24 scientists to SEAFDEC and the Southeast Asian countries in 2013. The over-all number of scientists and staff dispatched by FRA since the start of the formal cooperation totaled 105 scientists/fisheries managers.

The cooperation had therefore enabled a number of staff from SEAFDEC and officers from the ASEAN Member States to boost their capacity in conducting research and development activities in various fields of fisheries and aquaculture. Meanwhile, exchange of expertise had been facilitated through the dispatch of FRA scientists to serve as research partners, lecturers, resource persons, as well as scientists/fisheries managers serving as Deputy Chiefs of SEAFDEC Departments ensuring sound technical management of these Departments. Through such collaboration, the capacity of SEAFDEC towards science-based development and management of fisheries and aquaculture had been enhanced paving the way for the sustainable development of fisheries in the Southeast Asian region.

## Challenges and the Way Forward

The renewed collaboration between SEAFDEC and FRA is expected to heighten the efforts of SEAFDEC in attaining sustainable fisheries development and food security, and for eradicating hunger and poverty in the Southeast Asian region. These efforts could contribute to deeper socio-economic integration in the region and subsequently comprise the concrete contribution of SEAFDEC towards the realization of the ASEAN Economic Community by 2015. Furthermore, the assistance of FRA of Japan under the SEAFDEC-FRA collaboration which focuses on capacity building is also envisioned to nail the gap of the wide disparity of development in fisheries and aquaculture among the countries in the Southeast Asian region. It is therefore, a great challenge for SEAFDEC to take advantage of the technologies already developed by FRA in Japan and adapt these to the region through joint R&D programs with FRA.

Under the renewed SEAFDEC-FRA cooperation, five areas of work have been identified by SEAFDEC for possible technical assistance from FRA (**Box 2**). These include: (1)

**Box 1.** Technical assistance provided by FRA under the SEAFDEC-FRA Collaboration (Adapted from Matsusato, 2014a)

**1. Research on Special Topics**
- *Aquaculture technology development including fish pathology*
  - Publication of manual on **"Diseases of Cultured Groupers"** (2004) with SEAFDEC Aquaculture Department (AQD)
  - Joint research on **Larval Production of the Humphead Wrasse *Cheilinus undulatus*** (2010) with AQD
- *Fish stock assessment and management*
  - Collection of information on **Shark Fishery** (CITES issue) with SEAFDEC Marine Fishery Resources Development and Management Department (MFRDMD)
  - Publication of **"Sharks and Rays in Malaysia and Brunei Darussalam"** (2005) with MFRDMD and Department of Fisheries (DOF) Malaysia
  - Workshops on **Artificial Reefs** co-sponsored with MFRDMD and DOF Malaysia: Kuala Lumpur (2009), Bangkok (2009), Tokyo (2010)
  - Resource persons provided during the **Training on Juvenile Tuna Identification** at SEAFDEC/MFRDMD
- *Energy saving in fishing boat operations*
  - Resource persons and lecturers provided during **On-site Training on Energy Savings in Small Fishing Boats** organized by SEAFDEC Training Department (TD) in 2013 in Thailand, Vietnam, Myanmar
- *Seafood safety and food processing*
  - Resource persons and lecturers provided during the **Training on Analysis of Shellfish Poisoning** at SEAFDEC Marine Fisheries Research Department (MFRD)
- *Fishery management and economic research*
  - Awareness building through poster presentation on **"Fisheries Co-management in Japan"** with SEAFDEC Secretariat at Kasetsart University, Bangkok, Thailand (2014)

**2. Exchange of Expertise**
- *Dispatch of scientists/fisheries managers*
  - 24 scientists dispatched to SEAFDEC and Southeast Asian countries in 2013
  - A total of 105 scientists dispatched to SEAFDEC and Southeast Asian countries
  - 6 management staff dispatched to AQD and MFRDMD to serve as Deputy Department Chiefs while working as scientists/researchers

**3. Human Resource Development**
- *Training in Japan*
  - 5 trainees from SEAFDEC Departments accepted by FRA in 2013 (including those sponsored through Marino Forum 21)
  - Sponsored a total of 20 SEAFDEC staff and officers from ASEAN countries to train in Japan, since the start of SEAFDEC-FRA cooperation

| **Box 2.** R&D areas identified by SEAFDEC and proposed to FRA for technical assistance under the renewed SEAFDEC-FRA Collaboration | |
|---|---|
| ***R&D areas proposed by SEAFDEC to FRA for technical support*** | ***Remarks from FRA*** |
| **1. Stock assessment and enhancement of species with decreasing stock sizes** | |
| • Stock assessment and fishery management: the use of TAC System (MFRDMD) | • Ongoing, FRA technical support to be continued |
| • Genetic analysis of population and DNA barcode studies (MFRDMD) | • FRA technical support to be continued but study should also include DNA barcode for some commercially-exploited or endangered aquatic species |
| **2. Fish stock management with improved catch data compilation** | |
| • Responsible fishing and sustainable fisheries management (TD) | • Research studies on reduction of by-catch technology and discards and on development of technology in reducing manpower in fishing operations, are relevant to the region, thus, the project is being considered for possible FRA support<br>• Research on reduction of impacts of fishing to the coastal and marine environment might not be practical and needs thorough review |
| • Improving fish handling on-board small fishing vessels (TD) | • Could be carried out through the development of selective gears that target particular species, *e.g.* net design that catch only particular size/ species of fish |
| **3. Sustainable fisheries that sustain biodiversity and coastal environment** | |
| • Artificial reefs project (MFRDMD) | • Ongoing, FRA technical support to be continued |
| • Energy/fuel saving for fishing vessels/operations (TD) | • Research studies on appropriate design and techniques of fuel saving in fishing vessels and fishing operations, and on the use of LED for light fishing are relevant for the region, thus, being considered for FRA support<br>• Research study on alternative energy/fuel used in fishing vessels/engines might not be practical in actual fishing operations since filling of LPG and NGV for fishing vessels may not be possible in actual situations in Southeast Asia |
| **4. Aquaculture technology using artificially-raised juveniles** | |
| • Climate-resilient abalone ranching for small-scale fishers using hatchery-bred juveniles (AQD) | • Released spats might not contribute to the ability of species to undergo natural spawning and FRA is still establishing the reasons behind this. Moreover, studies on climate-resilient aquaculture should consider species that are tolerant to high temperature levels |
| • Aquaculture technology adoption pathways in Southeast Asia: study sites in Pampanga and Aklan in the Philippines; and in Vietnam and Myanmar (AQD) | • Being more of a regional activity, FRA could provide support through the extension of particular relevant technologies |
| • Establishment of environmental manipulation/ methods to develop boneless milkfish through suppression of intramuscular bone formation | • May not be very practical, however, adaptation of technology used in Japan, *e.g.* fish bone removal machine could be more suitable |
| **5. Development of vaccines against fish diseases for food safety** | • *Specific activity to be identified later* |

stock assessment and stock enhancement research on species with stock sizes that are alleged to be decreasing to protect these resources from declarations outside the fisheries sector that restrict the fisheries of such resources (*e.g.* species related to CITES); (2) fish stock management based on more detailed catch data compilation; (3) development of fisheries technologies that sustain biodiversity and the coastal environment; (4) aquaculture technology that does not reduce wild stocks, *i.e.* aquaculture using artificially-raised juveniles; and (5) development of vaccines against fish diseases for food safety. Considering that FRA is a research agency with budgetary allocations mainly for R&D programs (Matsusato, 2014b), SEAFDEC would formulate the research project proposals for cooperative work with FRA taking into consideration the aspects on institutional property rights (IPR) in the development of such proposals.

Further to the above remarks, the R&D areas that are being considered for technical assistance from FRA are aimed at ensuring stable supply of fishery products and developing robust fisheries industries in the Southeast Asian region (Matsusato, 2014b). In this regard, SEAFDEC is therefore developing joint R&D projects that promote technology development in order to attain such goal. Since FRA could also provide technical assistance on research initiatives not only targeting stable supply of fishery products but also securing safety of fishery products, SEAFDEC is therefore taking advantage of the opportunity to learn from the experiences on FRA in fisheries R&D.

**Experiences of FRA that could be adopted by SEAFDEC in promoting sustainable fisheries and aquaculture development in the Southeast Asian region**

With the onset of sustainable tuna management, the consequences of the technical assistance of FRA under its partnership with the Western and Central Pacific Fisheries Commission (WCPFC) could be learned by SEAFDEC. Specifically, SEAFDEC could avail of FRA expertise in analyzing various measures to promote tuna conservation, *i.e.* reducing the mortality of the bigeye tuna in fishing, and introducing the new and basic concept of controlling fishing effort, as well as in analyzing the impacts of the possible closure of FADs (Nakayama, 2014). As member of the WCPFC Scientific Committee, Japan through FRA is committed to compile and provide information on Japanese fishery and research to the WCPFC; provide standardized CPUE of Japanese fisheries as key indices for the stock assessment; conduct projects on tagging in the sub-tropical and temperate waters; develop new mitigation method of juvenile tunas catch on purse seine FADs operation; develop guidelines for the safe release of encircled whale shark by purse seine operation; develop and evaluate practical seabird mitigation methods; and collect tuna biological samples from Japanese markets. Such concerns could serve as models for SEAFDEC in formulating activities under its fisheries conservation projects for the sustainability of tuna resources in the Southeast Asian region.

SEAFDEC could also take up the recommendation of FRA for the development of appropriate cooperative management among relevant countries of Southeast Asia for the sustainable utilization of neritic tuna stocks based on scientific evidence. Neritic tunas are not appropriately managed under international cooperation in view of their characteristics as being evidently shared stocks among countries, especially in the Southeast Asian region (Nakayama, 2014). Considering that SEAFDEC has recently embarked on the Development of the Regional Plan of Action on Sustainable Utilization of Neritic Tunas in the ASEAN Region or RPOA-Neritic Tuna (SEAFDEC, 2014), the concerns of FRA on the sustainability of neritic tuna stocks could be useful in the development and promotion of the RPOA-Neritic Tuna in Southeast Asia.

Moreover, the experience of FRA in addressing concerns on the sustainability of cultured marine fish stocks could be grasped by SEAFDEC, especially with regards to controlling the viral nervous necrosis (VNN) infection in grouper. As reported by Nishioka *et al*. (2014), a variety of marine fish species, especially the economically-important grouper species, is affected by VNN caused by betanodaviruses, and their findings point to the fact that VNN occurs seriously during the seed production stage of grouper aquaculture. The FRA study made use of the long-tooth grouper *Epinephelus bruneus*, an economically-important marine fish, which inhabits the reef and coral areas of about 50 meters deep and substantially grows to marketable size.

Long-tooth grouper, *Epinephelus bruneus*

Following the protocols in the seed production of striped jack, virus free long-tooth grouper broodstock was selected based on PCR tests and naturally spawned fertilized eggs were placed in ozonated seawater. After hatching, the larvae and juveniles were reared with charcoal-treated ozonated seawater. As with the VNN control measure for striped jack, grouper sperm and eggs were cleaned, sperm activity and hatching rate of eggs examined including the level of virus removal. The sperms were placed on Percoll discontinuous gradients and centrifuged, then collected from the sperm-rich fraction beneath the 25% Percoll layer. While the results indicated 82% virus removal rate, cleaning did not influence the sperm activity and hatching.

FRA has also developed a vaccine which is now available on commercial scale, to control VNN infections in marine fish species. Although it has been found that VNN occurs mostly at early developmental stages, larvae or juveniles, but some fish species such as groupers and sea bass are susceptible to betanodaviruses even at the young and older stages (Mori *et al*., 2014).

Another most valuable marine fish species for aquaculture is the seven-band grouper *Epinephelus suptemfasciatus* which is highly susceptible to VNN infection even at grow-out stage. Records have shown that mass mortalities of this seven-band grouper could exceed 50% in net-pen aquaculture especially during the summer months. The effect of VNN on the fish could be characterized by upside down swimming with inflation of the swim bladder.

A vaccination project was therefore carried out by FRA from 2006 to 2008. This included studies on determining the vaccine strain, selecting vaccine candidate-fishes, establishing the effective vaccine dosage, and field-testing

Seven-band grouper *Epinephelus suptemfasciatus*

of vaccine developed (Mori *et al*., 2014). Results of the project pointed towards two injection vaccines that were found effective in inducing the protective immunity in seven-band grouper, *i.e.* recombinant vaccine and formalin-inactivated vaccine.

Although the recombinant vaccine is easy to prepare on a large scale, a booster injection is necessary to induce sufficient protection that must be a disadvantage in commercial vaccination practices. As a result of such disadvantage, formalin-inactivated vaccine was selected as a candidate. In the immunization experiment with different injection routes, *i.e.* intramuscularly (IM) or intraperitoneally (IP), the neutralizing antibodies were detected both in the immunized groups and there was no significant difference in the titers, although intraperitoneal route is preferable to prevent solution's leak in the injected sites (Mori *et al*., 2014). Based on the successful results from the field-testing experiments in 2008, the official approval for production and sale of the vaccine in Japan was obtained in 2012. The vaccine is now available on commercial scale in Japan and its distribution worldwide is expected to stabilize the aquaculture of groupers and increase the production of such economically-important aquaculture species.

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## About the Authors

**Ms. Virgilia T. Sulit** is the Managing Editor of the Special Publication *Fish for the People*, based at the SEAFDEC Secretariat in Bangkok, Thailand. She was a member of the Secretariat Team of SEAFDEC during the Signing Ceremony and Mini-Symposium on 10-year Achievements and Prospects for Future SEAFDEC-FRA Cooperation.

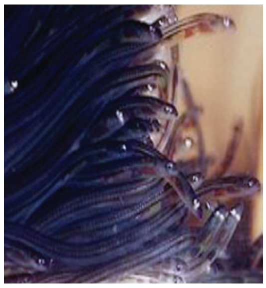
**Ms. Nualanong Tongdee** is the Information Program Coordinator of SEAFDEC and member of the Publication Team for this Special Publication *Fish for the People*, based at the SEAFDEC Secretariat in Bangkok, Thailand.

# Potentials and Prospects of Southeast Asian Eel Resources for Sustainable Fisheries and Aquaculture Development

*Somboon Siriraksophon, Felix G. Ayson* and *Virgilia T. Sulit*

The world demand for river eels has been increasing mainly because of the market expansion of some delicacies such as the *kabayaki* (broiled eel with sweet soy sauce) in East Asia. While most of the world's eel production is derived from aquaculture, it should be noted that eel aquaculture is still dependent on the natural resources. As techniques for the full-life cycle aquaculture of eels have not yet been fully developed for commercial use, the eel aquaculture industry is still solely dependent on wild resources for seed stocks. However, the natural resources had been confronted with various factors that could possibly create negative impacts on the eel resources including habitat alteration, overexploitation, climate change, pollution, and incidence of diseases. Thus, concerns on the sustainability of various eel species in the world have increased in recent years. It should be reckoned that the European and American eels are already threatened to certain degree by pollution and damming (or the construction of dams that prevent their migration to freshwater bodies) leading to almost "close to collapse" of the European eel resources. This situation prompted CITES to list the European eel (*Anguilla anguilla*) in CITES Appendix II in 2009 and accordingly, trade restrictions of the European eel and its products came into effect. In Southeast Asia, it is known that aquaculture and inland capture fisheries of eel are practiced but data and information on the total production of eel in the region remain very minimal. In this regard, the Southeast Asian countries have been encouraged to report their respective eel production to SEAFDEC in order that the status and trend of the region's eel resources could be established and the statistics could be appropriately reflected in the Fishery Statistical Bulletin of Southeast Asia produced yearly by SEAFDEC. Meanwhile, in an effort to conserve the eel resources in Southeast Asia, SEAFDEC recently launched a project on Conservation, Management and Sustainable Utilization of Eel Resources in Southeast Asia with funding support from the Trust Fund for SEAFDEC of the Fisheries Agency of Japan.

The eels being focused in the SEAFDEC Project on the Conservation, Management and Sustainable Utilization of Eel Resources in Southeast Asia, are those elongated fishes belonging to the genus *Anguilla* that mostly live the shallow waters and burrow in the sand, mud or between rocks, regularly inhabiting the freshwater areas, but returning to the sea to breed. Eels begin their life cycle as flat and transparent larvae known as leptocephali that drift



Photos from Ame (2014)

in the water surface of the sea and feed on small particles floating in the water. The eel larvae then metamorphose into glass eels and then become elvers before finally seeking out their juvenile and adult habitats. River eels, known as *unagi* in Japan are commonly used in Japanese and Chinese cuisines. In some countries in the Southeast Asian region, fishers consume the elvers as cheap source of protein, but environmental changes have reduced the eel populations, and elvers become costly. Considering the abundance of the Anguillid eel resources in the Southeast Asian region and the high demand for these species for famous cuisines make it necessary to manage the fisheries and aquaculture of such species. It is in this regard that SEAFDEC has started compiling information on the status and trend of eel resources in the region for the purpose of resource conservation and management of this economically-important commodity.

## Current Status of River Eel Resources in Southeast Asia

Although only Indonesia and Philippines had provided data on river eel production from inland capture fisheries (**Table 1**) to SEAFDEC (SEAFDEC, 2009-2013), results of a questionnaire survey conducted by SEAFDEC confirmed the abundance of eel resources in the waters of Southeast Asia (**Fig. 1**). However, no data had been made available on the aquaculture production of eel in the region.

**Table 1.** Production of river eel (*Anguilla* spp.) from inland capture fisheries (2007-2011), in metric tons (MT)

| Countries | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|
| Indonesia | 2,691 | 645 | 1,149 | 1,149 | 645 | 1,235 |
| Philippines | 688 | 710 | 835 | 719 | 867 | 1,149 |

***Sources:*** *Fishery Statistical Bulletin of Southeast Asia: 2007-2011 (SEAFDEC, 2009-2013), and Questionnaire Survey conducted by SEAFDEC in January 2014*

**Table 2.** Eel species found in the Southeast Asian region

| Countries | *Anguilla bicolor* (Indonesian short-fin eel) | *Anguilla celebesensis* (Celebes long-fin eel) | *Anguilla interioris* (Highlands long-finned eel) | *Anguilla japonica* (Japanese eel) | *Anguilla malgumora* (Indonesian longfinned eel) | *Anguilla marmorata* (marbled eel, giant mottled eel) | *Monopterus albus* (Asian swamp/ ricefield eel) |
|---|---|---|---|---|---|---|---|
| Indonesia | X | X | a | a | X | X | a |
| Malaysia | a | | | a | | X | a |
| Myanmar | | | | | | | X |
| Philippines | X | X | | X | | X | X |
| Thailand | X | | | | | | a |

**Sources:** *X = From questionnaire survey conducted by SEAFDEC in January 2014*
*a = Additional information from Prof. Dr. Takaomi Arai, Institute of Oceanography and Environment University, Malaysia*

The most common river eel species in the region are *Anguilla bicolor* found in Thailand, Indonesia, Malaysia and the Philippines, and *A. marmorata* in Indonesia, Philippines and Malaysia. Other eel species are also recorded in the Southeast Asian countries, such as *A. celebesensis* (= *A. ancestralis*), *A. japonica*, *A. malgumora* (= *A. borneoensis*), and *Monopterus albus* (**Table 2**).

Moreover, based on the inputs provided by the countries in the questionnaire survey, eel resources are abundant in many areas of Southeast Asia (**Fig. 1**). For example, in Indonesia, eels are found in Poso in Central Sulawesi, South Java, Benkulu in West Coast of Sumatra, and West Sulawesi. In Malaysia, eels are found in Sabah State, and in Myanmar, these are found in the Ayeyarwaddy Delta and in swamps along the coastal areas of the country. In the Philippines, eels are abundant in Cagayan Province (northern Luzon), Albay and Camarines Norte (eastern Luzon), Iloilo and Negros Occidental (central Philippines), and North Cotabato and Zamboanga del Sur (Mindanao). In Thailand, eels are found in Ranong, Phang-nga, Trang, and Satun Provinces.

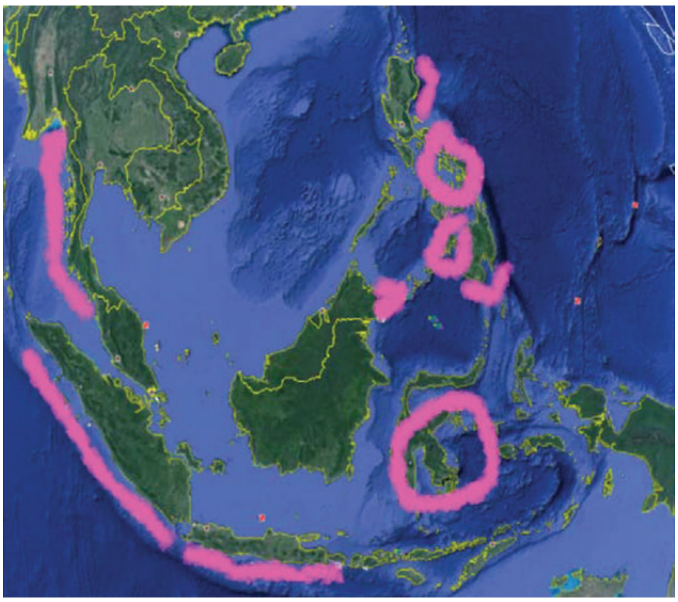
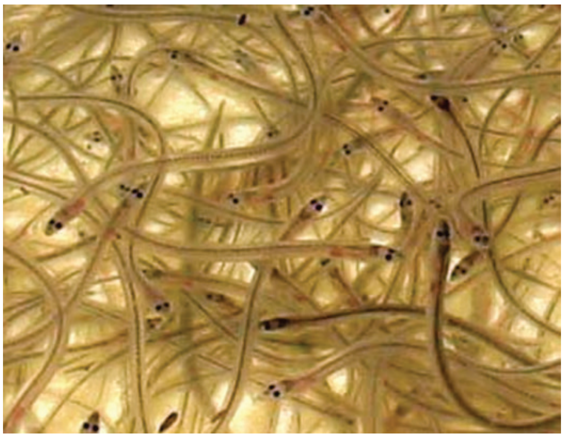


**Fig. 1.** Distribution of *Anguilla* spp. in Southeast Asia



Glass eel *(Photo from Maki (2014))*

Results of the questionnaire survey conducted by SEAFDEC in January 2014 also indicated that the most common gears used to catch *Anguilla* spp. in the Southeast Asian countries are: traps (Indonesia, Myanmar, Philippines, Thailand); scoop net (Indonesia); hook-and-line (Indonesia, Philippines); fyke net, bag net, push net, dip net, and B-gillnet (Philippines). Eels caught from the region are usually exported to the East and Southeast Asian countries, *e.g.* to Hong Kong (by Philippines); China (by Myanmar, Philippines); Japan, Taiwan, and South Korea (by Philippines); and to Thailand (by Myanmar). Indonesia was not able to indicate the importing countries for its eel products. It should also be noted that only Myanmar has a regulation on the catching and trading of eels, *i.e.* eels with body width of less than 3 cm are not allowed to be caught and exported. The results also showed that Indonesia and the Philippines have eel culture farms that make use of seeds, larvae and juveniles collected from natural waters. However, no specific data was provided, in terms of the number of eel culture farms, feed source and feeding management, average annual production, and farming systems applied. It is envisioned that through the effort being sustained by SEAFDEC, the status and trend of eel fisheries and aquaculture could be established soon.

## Research on River Eel Species Conducted in Southeast Asia

Many research studies on eel species have been conducted in many countries by many authors worldwide, however, only few could be considered as those that were conducted at the Southeast Asian setting. It should be reckoned that through such research efforts, a new species of river eel, *Anguilla luzonensis* was discovered in northern Luzon in the Philippines. Watanabe *et al*. (2009) described *A. luzonensis* on the basis of 29 specimens collected from the Pinacanauan River system, a tributary of the Cagayan River in northern Luzon. Some of the research studies relevant to eels in Southeast Asia by authors from Southeast Asia and collaborating partners are shown in **Table 3**.

From **Table 3** which forms part of a list on Research Information on Eel (Ayson, 2014), it can be observed that only few studies had been conducted on the culture of river eels. Nevertheless, it has been reported that about 10 companies operate eel culture farms in Indonesia while in the Philippines eel aquaculture has also started (Maki, 2014). Meanwhile, Pripanapong (2014) summarized the results of some experiments on true eel conducted in Thailand that focused on abundance and distribution, feeds and feeding habits, nursery, culture using pellet feeds and indifferent salinities. Thailand has also recorded the first female maturation of true eel in its coastal waters (Tongnunui *et al*., 2011).

**Table 3.** Research areas and major findings on river eels in Southeast Asia

| Eel Species | Topic of investigation | Major findings | Author(s) | SEA Country |
|---|---|---|---|---|
| *A. bicolor bicolor* | Biology (maturation) Life stages (adult) | *A. bicolor* in Malaysian waters matures within 4 to 6 years. Timing of maturation is similar with *A. japonica* but earlier than other temperate eels reported in previous studies. | Takaomi Arai (2013) | Malaysia |
| *A. celebesensis*<br>*A. interioris*<br>*A. nebulosa nebulosa*<br>*A. marmorata*<br>*A. borneoensis*<br>*A. bicolor bicolor*<br>*A. bibolo pacifica* | Genetics (species identification using PCR) | One pair of primer tested amplified a specific fragment of the DNA from each samples. The length of the PCR product was verified by DNA agarose gel electrophoresis. | Melta Rini Fahmi (2013)<br>Dedy Duryadi<br>Solihin Kadarwan<br>Soewardi<br>Laurent Pouyaud<br>Zhaojun Shao<br>Patrick Berrebi | Malaysia |
| *A. marmorata*<br>*A. bicolor pacifica* | Ecology (migration and habitat use)<br>Life stage<br>Yellow stage (immature)<br>Silver stage | Otolith strontium (Sr) and calcium (Ca) ratio of anguillid eels collected in Vietnam showed that *A. marmorata* could be a catadromous, constant residence in brackishwater and could shift between sea and brackishwater with no freshwater life.<br>*A. bicolor pacifica* has a general life history as a freshwater resident. The otolith Sr:Ca ratio after recruitment to coastal waters indicated that the habitat of these eels during their growth phases was facultative among fresh, brackish and marine waters. | Takaomi Arai (2013)<br>Naoko Chino<br>Dung Quang Le | Vietnam |
| *A. luzonensis* | Ecology (spawning area and early life history)<br>Life stage (leptocephalus) | Larvae collected from offshore western North Pacific of a recently discovered new eel species from Luzon was identified using DNA analysis. The species has long larval duration and hatching was estimated to fall in February to May. The offshore presence of the larvae and ocean current direction suggest that this species migrates to spawn in the north equatorial current (NEC). | Mari Kuroki (2012)<br>Michael Miller<br>Jun Aoyama<br>Shun Watanabe<br>Tatsuki Yoshinaga<br>Katsumi Tsukamoto | Philippines |
| *A. bicolor bicolor* | Ecology (species distribution) | *A. bicolor bicolor* has an extended species distribution range into Peninsular Malaysia. | T. Arai (2012)<br>N. Chino<br>S.Z. Zulkifli<br>A. Ismail | Malaysia |
| *A. marmorata* | Genetics (genetic variation and population history) | Sequences of the mitochondrial control region gene of *A. marmorata* from Hainan and Philippines were compared. The Philippine population exhibited higher variability than the Hainan population. A molecular phylogenetic tree analysis showed no significant genetic differences between the two populations. | Xu ding (2012)<br>Xin Qi<br>Shaowu Yin | Philippines |

**Table 3.** Research areas and major findings on river eels in Southeast Asia (Cont'd)

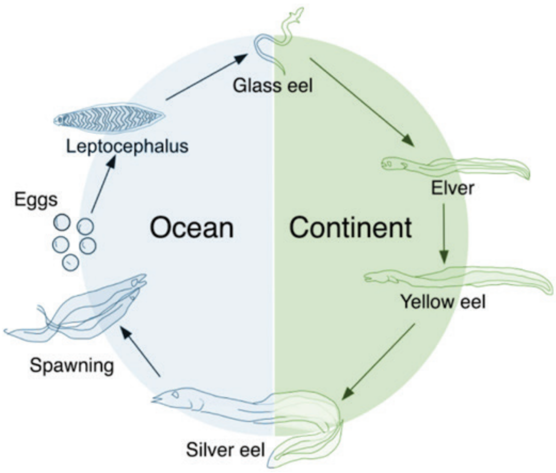
| Eel Species | Topic of investigation | Major findings | Author(s) | SEA Country |
|---|---|---|---|---|
| *A. bicolor* | Nutrition (effects of attractant on protein, fat and energy retention on eel juvenile<br>Life stage (elver) | Treatment without attractants added in paste feed showed best results in protein and energy retention while pasta feed with squid oil gave the best retention of fats in the muscle of *A. bicolor*. | S. Yudiarto (2012)<br>M. Arief<br>Agustono | Indonesia |
| *A. marmorata*<br>*A. bicolor pacifica* | Toxicology (organotin accumulation in fish migrating between sea and freshwater)<br>Life stage (yellow and silver stages) | Yellow-stage eels have a higher risk of tributylin contamination than silver-stage individuals. A positive relationship was found between Sr:Ca ratios, total tributylin and total phenyltins. Organotins in these eels increase with increasing sea residence period. | T. Arai (2011)<br>N. Chino<br>D.Q. Le<br>H. Harino | Vietnam |
| *A. bicolor bicolor*<br>*A. celebesensis*<br>*A. marmorata* | Ecology (life history and migration pattern) | Among the samples collected, no *A. bicolor bicolor* had a general life history as a freshwater resident. Its habitat use is facultative among fresh, brackish and marine waters during the growth phase after recruitment to coastal areas similar to that for temperate eels. Migration of anguillid eels into freshwater is not obligatory. | N. Chino (2010)<br>T. Arai | Indonesia |
| *A. marmorata* | Toxicology (trace metal and methylmercury contamination in soft tissues of eel)<br>Life stage (mature eel) | Liver and kidney of the eel were the dominant organs for all trace metals. Muscles accumulate high levels of mercury, and there was a strong positive correlation between mercury levels in muscle and age. Zinc was deposited in high concentration in the gonad and liver, and might play an important physiological role during gonadal maturation. | Dung Quang Le (2010)<br>Duc Cu Nguyen<br>Hiroya Harino<br>Naoya Kakutani<br>Naoko Chino<br>Takaomi Arai | Vietnam |
| *A. marmorata* | Toxicology (heavy metals contamination in muscle tissue of eel)<br>Life stage (juvenile-adult) | Concentration of heavy metal elements Cu, Cd, Cu, Zn, Co and Sr in muscles of *A. marmorata* varies among four provinces where samples were collected, while Mn and Pb did not vary among locations. | Quang Dung (2009)<br>Kotaro Shirai<br>Duc Cu Nguyen<br>Nobuyuki Miyazaki<br>Takaomi Arai | Vietnam |
| *A. marmorata*<br>*A. bicolor pacifica*<br>*A. bicolor bicolor* | Ecology (migration and habitat preferences of eels in Cagayan and Kalinga Province, Philippines)<br>Life stage (growth phase/ yellow stage) | Through otolith microchemistry, the life history and migratory patterns of 22 eel samples collected from three rivers in Northern Luzon were reconstructed. While *A. marmorata* is freshwater-oriented, *A. bicolor bicolor* prefers estuarine environment, and *A. bicolor pacifica* is a marine oriented species. | Alex A. Briones (2007)<br>Apolinario V. Yambot<br>Jen-Chieh Shiao<br>Yoshiyuki Iizuka<br>Wann-Nian Tzeng | Philippines |
| *A. bicolor bicolor* | Ecology (early life history and location of spawning ground)<br>Life stage (glass eel) | *A. bicolor bicolor* was the dominant species of glass eel collected during early migration from the Indian Ocean to West Java. | Budimawan (2007)<br>R Lecomte-Finiger | Indonesia |
| *A. bicolor bicolor* | Fish Health (parasites found on eel in Thailand) | *Procamallanus anguillae* is a new species of parasitic nematode recovered from intestines of *A. bicolor* from Thailand. Two other species of larval nematodes, *Physalopteridae* and *Anisakis* were also recorded from this species. | F. Moravec (2006)<br>H. Taraschewski<br>M. Thairungroj<br>Anantaphruti<br>W. Maipanich<br>T. Laoprasert | Thailand |
| *A. bicolor* | Reproduction (effects of light and salinity on ovarian development) | Long illumination influenced ovarian development on eels in freshwater conditions. | I. Heriyanti (2005) | Indonesia |
| *A. marmorata*<br>*A. bicolor pacifica*<br>*A. celebesensis*<br>*A. borneoensis* | Ecology (migration and early life history) Life stage (leptocephalus, glass eel) | Growth rates of two eel species, *A. celebesensis* and *A. borneoensis* that spawned near Indonesia were faster than two species that spawned in Western North Pacific (WNP) where *A. bicolor pacifica* had higher growth rate than *A. marmorata*. Maximum size of leptocephali for all four species is similar at about 50 mm TL. | Mari Kuoki (2006)<br>Jun Aoyama<br>Michael J. Miller<br>Sam Wouthuyzen<br>Takaomi Arai<br>Katsumi Tsukamoto | Indonesia |
| *A. marmorata* | Ecology (inshore migration)<br>Life stage (glass eel) | Glass eels were active at night, with high activity observed between 0200-0400 hrs. Their migration was initiated by increase in water flow. Migration peak occurred in January- March. Duration of the larval stage was estimated to be 87-102 days. | Budimawan (2005)<br>R. Lecomte-Finiger | Indonesia |

**Table 3.** Research areas and major findings on river eels in Southeast Asia (Cont'd)

| Eel Species | Topic of investigation | Major findings | Author(s) | SEA Country |
|---|---|---|---|---|
| *A. celebesensis* | Biology (larval duration, age of metamorphosis and recruitment) | Metamorphosis is a key factor in larval migration that is related to inshore migration of glass eels. The age of metamorphosis and age of recruitment of *A. celebesensis* from Indonesian coasts is shorter than the recruits from the Philippines, suggesting shorter distance between spawning area and recruitment area than those in Philippine coasts. | Takaomi Arai (2003)<br>Michael J. Miller<br>Katsuni Tsukamoto | Philippines |
| *A. celebesensis*<br>*A. marmorata*<br>*A. bicolor pacifica* | Ecology (early life history and migration) | Spawning and inshore migration of silver-stage eels for each species were all year-round and age at recruitment was constant. This indicates year-round migration in tropical rivers, in contrast with temperate eel species. | Takaomi Arai (2003)<br>Michael J. Miller<br>Katsuni Tsukamoto | Indonesia |
| *A. marmorata* | Nutrition (effects of various diets on growth) | | N.P. Nam (2003) | Vietnam |
| *A. marmorata* | Ecology (early-life history and recruitment in the Western North Pacific)<br>Life stage (glass eel) | New collected samples from Japan, Taiwan and Indonesia were compared with previous published samples. The average duration of the period of metamorphosis estimated from otolith microstructure was very similar in all locations. Specimens from all sampling sites are from the same spawning population originating in a spawning area in NEC of the WNP. | Takaomi Arai (2002)<br>M. Marui<br>M.J. Miller<br>K. Tsukamoto | Indonesia |
| *A. marmorata* | Ecology (period of deposition of growth increments in the otolith of tropical eel)<br>Life stage (glass eel) | Glass eels were immersed in an alizarin solution to mark their otoliths and were returned to their natural environment. These eels were recollected after 20 days and growth rings were examined on their otoliths. The growth increments found in the otoliths coincided with the days passed after otolith marking. | H.Y. Sugeha (2001)<br>T. Arai<br>M.J. Miller<br>D. Limbong<br>K. Tsukamaoto | Indonesia |
| *Anguilla* sp. | Aquaculture: culture of anguillids | Culture of eel (*Anguilla* spp.) in the Philippines is discussed. Market potentials for the cultured products are examined. | A.P. Surtida (2000) | Philippines |
| *A. celebesensis*<br>*A. marmorata*<br>*A. bicolor pacifica* | | Linear relationships were observed between age at metamorphosis and age at recruitment, suggesting that early metamorphosing larvae were recruited to freshwater habitat at an early age. Recruitment of glass eel to the river mouth was year-round unlike temperate eel species. | T. Arai (2001)<br>J. Aoyama<br>S. Ishikawa<br>M.J. Miller<br>T. Otake<br>I. Inagaki<br>T. Tsukamoto | Indonesia |
| *A. celebesensis*<br>*A. marmorata*<br>*A. bicolor pacifica* | Ecology (species composition, early-life history species migration)<br>Life stage (glass eel) | *A. celebesensis* and *A. marmorata* were collected throughout the year. More glass eels were collected at Poigar River during new moon and during flood tide. | H.Y. Sugeha (2001)<br>T. Arai<br>M.J. Miller<br>D. Limbong<br>K. Tsukamaoto | Indonesia |
| *A. celebesensis*<br>*A. marmorata*<br>*A. bicolor pacifica* | Population (species composition and identification based on morphology and mitochondrial DNA)<br>Life stage (glass eel) | Glass eels occur all throughout the year. *A. celebesensis* was the most dominant (70%), found all year round except in March and September. The second dominant species was *A. marmorata* (23%), and was seen all throughout the year. *A. bicolor pacifica* was the least dominant (7%) occurred in January, March, April, October and December. | Takaomi Arai (1999)<br>Jun Aoyama<br>Daniel Limbong<br>Katsumi Tsukamoto | Indonesia |
| *A. bicolor pacifica* | Ecology (early life history and recruitment mechanism)<br>Life stage (glass eel) | Otolith microstructure revealed the age of recruitment of the glass eel samples which ranged from 124 to 202 d, and metamorphosis ranged from 101 to 172 d. The fluctuation patterns in otolith increment widths and Sr:Ca ratios were similar to those of temperate eels. | Takaomi Arai (1999)<br>T. Otake<br>D. Limbong<br>K. Tsukamoto | Indonesia |
| *A. bicolor* | Fish Processing (quality of smoked eel in different salt percentage and smoke) | Literature in Bahasa Melayu | Suprayitno *et al.* (1998) | Indonesia |

**Table 3.** Research areas and major findings on river eels in Southeast Asia (Cont'd)

| Eel Species | Topic of investigation | Major findings | Authors | SEA Country |
|---|---|---|---|---|
| *A. marmorata*<br>*A. japonica*<br>*A. celebesensis* | Ecology (species identification and distribution)<br>Life stage (leptocephali) | Eight specimens collected by a Japanese research vessel in the waters east of Luzon comprised 7 *A. Japonica* and 1 that was either *A. marmorata* or *A. celebesensis*. Youngest leptocephali larvae of *A. japonica* collected from the field were also found in the survey specimens. | T. Ozawa (1989)<br>O. Tabeta<br>N. Mochioka | Philippines |
| *A. japonica*<br>*A. bicolor pacifica*<br>*A. marmorata* | Ecology (species distrubution and composition)<br>Life Stage (leptocephali) | Leptocephali were collected from south of Okinawa and east of Taiwan and in Luzon. *A. japonica* made up majority of the samples (21), 5 were *A. marmorata* and/or *A. celebesensis*, and 1 was *A. bicolor*. | O. Tabeta<br>N. Mochioka (1988) | Philippines |
| *A. celebesensis*<br>*A. marmorata*<br>*A. japonica*<br>*A. bicolor pacifica* | Ecology (species composition and seasonal occurrence)<br>Life stage (elver) | Elvers collected from Cagayan estuary and neighboring eel ponds were composed of *A. marmorata* and *A.celebesensis* as dominant species and *A. bicolor pacifica* and *A. japonica* as minor species. Elvers occurred most of the year but were most abundant in March and August. | O. Tabeta (1976)<br>T. Tanimoto<br>T. Takai<br>I. Matsui<br>T. Imamura | Philippines |
| *A. bicolor* | Biology (unusual eye size observed from a specimen) | Specimen was described and the unusual size of the eye was viewed as adaptation for navigation. | G.R. Williamson<br>P.H.J. Castle (1975) | Indonesia |
| *A. bicolor*<br>*A. marmorata*<br>*A. celebesensis* | Ecology (species identification, distribution, relative abundance and culture feasibility)<br>Aquaculture (some details noted on culture experiments and tour of commercial culture operation) | Elvers of these species migrated simultaneously. Commercial quantities of elvers were found only in Cagayan River. *A. bicolor* was the only species suitable for culture. Its elvers grew well on ground fish with vitamin additives and showed 6:1 feed conversion. Pelleted feeds were desirable for fingerlings and large eels (>3g). | M.C. Cremer (1976) | Philippines |
| *A. bicolor pacifica*<br>*A. bicolor*<br>*A. marmorata*<br>*A. celebesensis* | Aquaculture (prospect of eel industry in the Philippines)<br>Life stage (elver) | Aquaculture practices in Cagayan Province, Philippines on rearing eel elvers were described in this BFAR report. | P. Gutierrez (1973) | Philippines |




Life cycle of river eels

*(Prisantoso, 2014)*

## Prospects for Sustainable Aquaculture Development

Currently, the largest aquacultured eel species in terms of production volume is the Japanese eel (*Anguilla japonica*). However, catch of elvers and juveniles for aquaculture seeds have slumped since 2010 in the whole region, especially in the Philippines (Ame, 2014) resulting in the rising prices of the seeds for aquaculture. Thus, interests in the development of other eel species juveniles as cheaper alternatives have been growing. The establishment of measures to ensure sustainable utilization of eel resources in the region should therefore be considered as an urgent task.

Nevertheless, in the eel aquaculture industry, various constraints have emerged, such as unstable glass eel and elver supplies, lack of knowledge on larval rearing, disease occurrences, inconsistent product quality, limited markets, and lack of culture techniques for other eel species. The

*Elvers (Prisantoso, 2014)*

challenge is to overcome these constraints in a sustainable manner taking into account the technical, environmental, and economic considerations.

## Way Forward

In order to ensure the sustainable utilization of eel resources in Southeast Asia, SEAFDEC was given the task by the Member Countries to spearhead the conduct of a study on eel resources in the region including the need to assess the prospects for sustainable aquaculture development and management in the future. To start such endeavor, SEAFDEC embarked on a new Project on "Conservation, Management and Sustainable Utilization of Eel Resources in Southeast Asia" being implemented as a collaborative effort of the SEAFDEC Secretariat and three Departments, namely: Marine Fishery Resources Development and Management Department (MFRDMD) based in Malaysia, Aquaculture Department (AQD) in the Philippines, and the soon-to-be established Inland Fishery Resources Development and Management Department (IFRDMD) in Indonesia. The Project intends to come up with compiled information on the distribution and status of eels in the Southeast Asian region, proper sequences that can be used to identify the species of eels found in the region, trained personnel capable of identifying eel species, and responsible culture techniques for river eels taking into account economic, technical, and environmental considerations.

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### About the Authors

**Dr. Somboon Siriraksophon** is the SEAFDEC Policy and Program Coordinator based at the SEAFDEC Secretariat in Bangkok, Thailand.

**Dr. Felix G. Ayson** is the Chief of SEAFDEC Aquaculture Department based in Iloilo, Philippines.

**Ms. Virgilia T. Sulit** is the Managing Editor of *Fish for the People* based at the SEAFDEC Secretariat in Bangkok, Thailand.

# Mutual Partnership between Fish Hatchery Operators and Growers for Sustainable Aquaculture Development:
## A Case in Cambodia

*Chin Leakhena*

This article is based on the author's research study on the Assessment of Local Seed Production in Takeo and Kampong Speu Provinces of Cambodia, in partial fulfillment of the requirements for her to obtain the Master's of Science degree in Aquaculture and Aquatic Resources Management from the Asian Institute of Technology, Thailand. Conducted from 2012 to 2013, the study was focused on Takeo and Kampong Speu Provinces being the country's center for freshwater fish seed production and grow-out activities, and where the relationship between fish hatchery operators and growers is being assessed to determine its effect on the sustainable development of freshwater aquaculture in Cambodia.

Freshwater aquaculture is an important component of the fisheries sector of Cambodia not only because of its abundant freshwater resources for potential aquaculture development but also considering that freshwater aquaculture could provide the means of increasing peoples' incomes and creating livelihoods in rural communities. During the early part of the country's freshwater aquaculture development, fish growers were confronted with insufficient supply of seed stocks resulting in their complete reliance on seeds from the wild which later became unsustainable or on imported fish seeds that usually commanded exorbitant prices. Later on, the Royal Government of Cambodia promoted the production of locally-produced fish seeds by providing technical support to local freshwater fish hatchery operators. Meanwhile, fish growers were also encouraged to patronize locally-produced fish seeds for their fishpond requirements.

Freshwater aquaculture of Cambodia has exhibited potentials to increase the country's total fisheries production and supply the necessary nutritional requirements of its people as well as increase the country's fisheries export volume. In 2011 for example, the country's total fisheries production was recorded at 631,695 metric tons (MT) of which freshwater aquaculture accounted for about 11% (**Table 1** and **Fig. 1**). It is obvious that if properly managed and sustained, such rate of increase in production could be improved much better than the average annual rate during the past five-year period from 2007 to 2011. Since fish seed producers are instrumental in providing the necessary seed inputs for fish growers, it has become crucial to enhance the mutual relationship between these two major stakeholders in order that positive impacts could be gained from such partnership for the sustainable development of freshwater aquaculture in Cambodia, and eventually, increasing the contribution of freshwater aquaculture to the overall goal of providing adequate food fish and incomes for the country's rural communities.

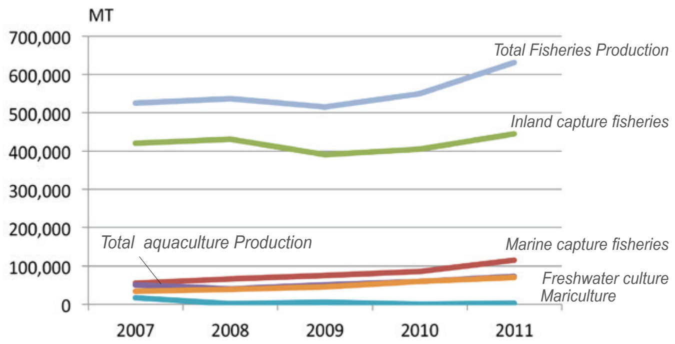


**Fig. 1.** Fisheries production trend of Cambodia
**Note:** Production from freshwater culture is almost equal to total aquaculture production

As shown in **Fig. 1**, Cambodia's production from freshwater aquaculture is almost equal to its production

**Table 1.** Total fisheries production of Cambodia, 2007-2011 (in metric tons (MT))

| Categories | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|
| Marine capture | 54,900 | 66,000 | 75,000 | 85,000 | 114,695 |
| Inland capture | 420,000 | 430,600 | 390,000 | 405,000 | 445,000 |
| Aquaculture | | | | | |
| *Mariculture* | 16,630 | 1,370 | 4,925 | -- | 2,620 |
| *Brackishwater* | -- | -- | 75 | -- | -- |
| *Freshwater* | 33,570 | 38,350 | 45,000 | 60,000 | 69,380 |
| **TOTAL** | **525,100** | **536,320** | **515,000** | **550,000** | **631,695** |

***Sources:*** *Fishery Statistical Bulletin of Southeast Asia: 2007-2011 (SEAFDEC, 2010a, 2010b, 2011, 2012, 2013)* from aquaculture in general. Thus, boosting the country's aquaculture production to secure incomes and livelihoods in rural areas is synonymous to improving its freshwater aquaculture. In an effort to address the major constraint on insufficiency of quality seeds, the Royal Government of Cambodia has deemed it necessary to develop the local freshwater fish hatcheries in order that future demands for seed stocks of the country's freshwater aquaculture industry could be fulfilled without unnecessarily relying on imported fish seeds or seeds collected from the wild.

## Status of Freshwater Aquaculture in Cambodia

Fish cage and pen culture is a historical practice in Cambodia that spans over 1,000 years (Pe and Bun, 2005 cited in FiA, 2010a). Developed since the 10th century, fish fattening in bamboo cages and pens had been carried out especially during the closed fishing season (Nam and Thuok, 1999a). The country's aquaculture therefore started as a fish fattening system using wild caught fingerlings to increase the market price of fish. Recently, such system has evolved into a more advanced fish farming practice using fishponds. Although aquaculture provides a relatively small contribution to the total fisheries production of the country, *i.e.* at 11% in 2011 while capture fisheries accounted for 89%, the constantly increasing production from aquaculture, *i.e.* from 50,200 MT in 2007 to 72,000 MT in 2011, demonstrates the huge potentials for developing this sector into an industry that the country could depend on for improved nutrition of its populace and increased economies in the future. At present, the country's aquaculture development is highly diverse consisting of broad spectrum of systems, practices and operations, ranging from simple backyard-small household pond systems to large-scale, highly intensive, commercially-oriented practices (Nam and Thuok, 1999b; Nam and Buoy, 2005).

While the country's inland fisheries grew rapidly with total production ranging from 420,000 MT in 2007 to 445,000 MT in 2011 after the fisheries sector reform program of Cambodia was adopted in 2000, freshwater aquaculture production also exhibited speedy growth from 33,570 MT in 2007 to 69,380 MT in 2011 (**Table 1** and **Fig. 1**). Just like in most countries of Southeast Asia, aquaculture in Cambodia is also classified into mariculture, brackishwater culture and freshwater culture, where the latter is mostly practiced in cages/pens and ponds (Nam and Buoy, 2005). Freshwater aquaculture facilities are mostly maintained in the Mekong River Basin, *i.e.* in the upper stretch of the Mekong River (19%), lower stretch of Mekong River (14%), Bassac River (7%), Tonle Sap River (17%), and Tonle Sap Great Lake (42%). While the number of fish cages had been more or less stable at 4,492 units during the past 10 years until 2004, this dropped to 2,588 in 2005 due to the country's ban on snakehead fish culture but increased to 3,883 in 2012 (**Table 2**). Nam and Thuok (1999a) reported that 72% of the country's annual freshwater aquaculture production generally comes from cage/pen culture and only about 28% from pond culture.

Although Cambodia has no tradition of culturing fish in earthen ponds in rural areas due to difficulties in keeping water in ponds during the dry season, the number of ponds had rapidly increased from 3,455 in 1997 to 11,509 in 2004, an increase of 43% during an eight-year period (Nam and Buoy, 2005), and in 2012 the number had increased to 53,452 more than one third of which are found in Takeo Province (**Table 2**). This development was brought about by the priority given to aquaculture in the country's national development agenda to improve food security and living standards of its people, as well as balance the declining fish catch from the wild and highly increasing local demand for food fish. As a consequence, it has become necessary to increase the production of fish seeds from hatcheries to fulfill the requirements of the country's rapidly growing aquaculture industry (Viseth, pers. comm. 2012). Thus, in 2012 the number of fish hatcheries totaled 280, of which 266 are operated by private-farmers and 14 are public hatcheries, producing a total of about 130 million fingerlings in 2012 representing a 3.5 times increase over the past four years, *i.e.* from 37.2 million fingerlings in 2008 (FiA, 2012).

In the late 1980s, many NGOs and donor-funded development projects assisted the Royal Government of Cambodia in developing the country's rural freshwater small-scale aquaculture after recognizing the potential role of aquaculture in the country's socio-economic development. The activities then were mostly focused on transferring aquaculture technologies to fish farmers

Typical village fish hatchery in Takeo Province, Cambodia

**Table 2.** Number of aquaculture facilities in Cambodia (as of 2012)

| Province | Culture Ponds | Culture Cages | Hatcheries | | | Community Refuge Ponds |
|---|---|---|---|---|---|---|
| | | | Total | Private | Public | |
| Phnom Penh | 201 | 147 | 4 | 3 | 1 | 13 |
| Kandal | 554 | 733 | 12 | 11 | 1 | 25 |
| Prey Veng | 9,082 | 160 | 22 | 21 | 1 | 69 |
| Takeo | 19,146 | 12 | 37 | 36 | 1 | 58 |
| Svay Rieng | 9418 | - | 17 | 16 | 1 | 24 |
| Kampong Speu | 1,824 | - | 24 | 23 | 1 | 173 |
| Kampong Cham | - | 610 | 15 | 15 | 0 | 21 |
| Kratie | 550 | 90 | 10 | 9 | 1 | 10 |
| Stung Treng | 380 | 3 | 5 | 5 | 0 | 3 |
| Kampong Thom | 160 | 137 | 6 | 6 | 0 | 27 |
| Kampong Chhnang | 501 | 483 | 7 | 7 | 0 | 21 |
| Pursat | 1,660 | 755 | 9 | 8 | 1 | 16 |
| Battambang | 1,150 | 560 | 25 | 23 | 2 | 23 |
| Banteay Meanchey | - | - | 13 | 12 | 1 | 22 |
| Oudarmean Chey | - | - | 3 | 2 | 1 | 11 |
| Siem Reap | 500 | - | 11 | 10 | 1 | 92 |
| Ratanakiri | 419 | - | 13 | 13 | 0 | 11 |
| Mondolkiri | 389 | - | 6 | 6 | 0 | 3 |
| Preah Vihear | 400 | 8 | 7 | 7 | 0 | 14 |
| Kampot | 7,000 | 50 | 27 | 26 | 1 | 69 |
| Preah Sihanouk | - | - | 3 | 3 | 0 | 20 |
| Koh Kong | 118 | 135 | 4 | 4 | 0 | 13 |
| **TOTAL** | **53,452** | **3,883** | **280** | **266** | **14** | **738** |

***Sources:*** *FiA (2012)*

through training and demonstration activities; establishing provincial stations for fish seed production and extension services; promoting private hatcheries development (*e.g.* small-scale village fish hatcheries); building the capacity of government fisheries officers and staff; and to certain extent, supporting on-farm and on-station research activities. As a result of the collaborative efforts between the Fisheries Administration (FiA) of the Ministry of Agriculture, Forestry and Fishery of Cambodia and the NGOs and donor organizations, small-scale freshwater aquaculture has been promoted throughout the country.

Such development was mainly aimed at generating alternative livelihoods, increasing household incomes and securing the protein source for the country's populace. The major fish species produced from Cambodia's freshwater aquaculture include tilapia (*Oreochromis niloticus*), silver barb (*Barbonymus gonionotus*), common carp (*Cyprinus carpio*), silver carp (*Hypophthalmichthys molitrix*), Indian carp (*Labeo rohita*), Mrigal (*Cirrhinus mrigala*), catfish (*Pangasianodon hypophthalmus*), walking catfish (*Clarias batrachus*), and other species.

A decade later, culture-based fisheries management or community-based management of communal fish refuge ponds was initiated in Cambodia in 1990s for the main purpose of enhancing the natural freshwater fish stocks for integrated rice-fish culture. This involved releasing of broodstock of indigenous fish species into community ponds categorized as public property. Managed by local communities, these ponds are protected mainly for fish spawning. From these community ponds, fish juveniles or fingerlings as well as broodstock are allowed to migrate to inundated rice fields through connecting canals. In 2012, the total number of community fish refuge ponds was 738, including 173 in Kampong Speu (**Table 2**). It has been reported that local households could catch about 349 kg/household/year of fish from this system when management was done by the local communities (Thuok, 2009).

## Source of Seeds for Freshwater Aquaculture

The development of freshwater fish hatcheries was initiated in Cambodia during the last two decades when fish fingerlings from the wild had rapidly declined due to various factors such as overfishing, illegal fishing, deforestation, and changes in the environment. With the increasing importance given to aquaculture and recognizing the role of hatcheries to ensure timely availability of seeds in all areas of the country, the Royal Government of Cambodia embarked on an intensified development of the country's freshwater fish hatcheries. As a result, the number of hatcheries increased to 280 in 2012 and consequently, fish seed production also increased from 7.5 million heads in 2000s to 130.0 million heads in 2012.

The country's first known fish hatchery was built in Phnom Penh Municipality in 1984 (DoF, 2004). In order to supply the increasing demand for fish seeds, another hatchery was established at the Chak Angre vicinity also in Phnom Penh. Aside from seed production, both stations also embarked on fish culture operations to generate sufficient income for operations (DoF, 2004). Furthermore, in 1990s three NGOs, namely: the Partnership for Development in Kampuchea (PADEK), Southeast Asian Outreach (SAO), and Australian People for Health, Education and Development Abroad (APHEDA) also supported the establishment of provincial level fish seed production centers in Prey Veng, Kandal, and Kampot Provinces, respectively. At the start, these centers provided training and fish seeds to fish farmers but due to the increasing number of fish farmers involved and the considerably far distance of grow-out ponds from the hatcheries, sufficient and timely fish seed supply and extension support services became major constraints. These were addressed through the development of decentralized seed production centers and village-based farmer-led extension systems, which later proved to be beneficial because of easy accessibility by fish farmers and increased survival of seeds, resulting in fish farmers' acceptance of locally-produced fish seeds and good relationship between fish seed producers and grow-out operators.

In the mid 1990s, seed production centers were established in the northern provinces of Pursat, Battambang and Banteay Meanchey by a UNDP-funded project on Cambodia's Rehabilitation and Reconstruction (CARERE). However, operations stopped when the project phased out its activities in 1999, except for two stations in Pursat that remain operational until present. Another center was later built in Siem Reap with technical support from the Coopération Internationale Pour le Développement (CIDSE), Adventist Development and Relief Agency (ADRA) and World Food Program (WFP), but when their supports were phased out hatchery operations also ceased. Meanwhile, Japan International Cooperation Agency (JICA) and a micro-finance institution PRASAC supported the development of freshwater fish hatcheries in Takeo and Kampong Speu Provinces but were confronted with frequent environmental problems like floods and administrative problems such as financial and human resources, leading to irregular seed production activities. PRASAC also supported the establishment of another hatchery in Svay Rieng Province in the late 1990s which became operational until 2003 (DoF, 2004).

**Private sector hatcheries**

Seed production centers established in Cambodia were large-scale, medium-scale and small-scale. While large- and medium-scale private sector hatcheries have wide distribution networks from the far north province of Ratanakiri to the far south province of Preah Sihanouk, the distribution channels for small-scale hatcheries are limited to provincial and district levels, even if many small-scale hatcheries have the capability of producing large quantities of fish seeds, especially those located in Takeo, Prey Veng and Kandal Provinces (Viriyak *et al*., 1999). Nevertheless, most fish hatcheries have been confronted with various constraints such as insufficient water supply which is highly dependent on the monsoon season, inadequate skilled staff and operating budget, inadequate security to prevent theft and poaching, occurrence of predators, as well as unavailability and inaccessibility of hormones for induced spawning of broodstocks, limited nursery areas, ineffective marketing skills, inadequate extension support services, and poor or no access to information. Specifically for the small-scale hatcheries, the key challenges encountered include inadequate knowledge and training, difficulties in purchasing and sourcing hormones for induced spawning, and inefficient transportation systems for the fish seeds (Viriyak *et al*., 1999; Nam and Haing, 2007). Generally, small-scale hatcheries sell their fry to small-scale nurseries but when the hatcheries could no longer supply the increasing demand, nursery operators purchase fry from large- and medium-scale hatcheries. Fish nursery operators play an important role in providing informal credit to grow-out farmers, with the condition that farmers pay the cost of fish seeds at harvest time rather than at the time of purchase.

**Public sector hatcheries**

Government-controlled large-scale hatcheries were also established but were confronted with insufficient operational budget, as well as predation and poaching as in the case of the hatcheries established in Bati District (Viriyak *et al*., 1999). Other constraints encountered by public sector hatcheries include inadequate skilled human resources, insufficient fund allocation, inaccessibility to information and modern techniques, inaccessibility to transportation, and unclear operation mandates (Nam and Leap, 2007).

Thuok and Viseth (2004) reported that public and NGO-supported hatcheries have also been operating culture activities to generate additional income. When PADEK, SAO and APHEDA phased out their supports to public

hatcheries, fish seed producers had difficulties in seeking government funds to defray their fixed and operational expenditures and continue performing their mandates. As a result, their hatcheries were turned into profit-generating centers from the sale of fish seeds, fish grow-out production and training. Moreover, with sustainable seed production operations, the hatchery centers have also been involved in conducting research to develop and improve the culture technologies intended for small-scale fish farmers (Thuok and Nam, 2004). Although the mandate of most public hatcheries is to produce fish seeds and carry out extension activities, inadequate resources led to the conduct of few or no extension activities while only few public NGO-supported hatcheries include research activities as part of their mandates (DoF, 2004). Insufficient human resource is a major limitation for most hatcheries, as technical and highly-skilled staff preferred to work in high-paying jobs to earn their living and provide the basic needs of their families.

### Imported fish seed stocks

Fish farmers in Cambodia had been importing fish seeds from neighboring countries to fulfill their grow-out requirements since locally-produced fish seeds were not sufficient. In 2004, seeds of nine fish species including exotic species were imported, *e.g.* hybrid catfish (*Clarias gariepinus* x *C. batrachus*), tilapia, silver carp, mrigal, common carp, grass carp (*Ctenopharyngodon idella*) and other three indigenous species such as the sutchi catfish (*Pangasianodon hypophthalmus*), giant gourami (*Osphronemus goramy*) and climbing perch (*Anabas testudineus*), where about 60 million fingerlings were bought and brought into the country to supply the demands of pond and cage aquaculture (Nam, 2007). The main exporting country was Vietnam although Thailand, to lesser extent, also exported fish seeds. Of these imported species, the two most important are the hybrid catfish and tilapia contributing about 82% to the total imported fish seeds (63% and 19%, respectively). Such proportion of imported hybrid catfish was expected to increase because the species could replace the giant snakehead in cage culture, which was banned by the Government in the mid 2005 due to its significant dependence on small and wild fish for its diet (Nam *et al*., 2005), notwithstanding the negative impacts brought to the aquatic environment by escapees of the hybrid catfish. The other important imported species are silver carp, sutchi catfish, mrigal, common carp, grass carp, and to certain extent giant gourami and climbing perch (**Table 3**). Inadequate regulations on importation of fish seeds in the country allegedly increased the number of unlicensed traders or small companies that have been illegally importing fish seeds mostly from Vietnam and Thailand reaching as high as 200 million fingerlings per year (Kimleang, 2005). At certain point, Takeo and Kampong Speu encountered problems on the marketing of locally-produced fish seeds due to competitions with imported seeds.

**Table 3.** Species of fish seeds imported by Cambodia (2004)

| Fish species | No. of fingerlings | Percentage (%) |
|---|---|---|
| *Clarias gariepinus* x *C. batrachus* | 41,000,000 | 68.3 |
| *Oreochromis niloticus* | 11,500,000 | 19.2 |
| *Hypophthalmichthys molitrix* | 3,000,000 | 5.00 |
| *Pangasianodon hypophthalmus* | 1,500,000 | 2.50 |
| *Cirrhinus cirrhosus* | 1,200,000 | 2.00 |
| *Cyprinus carpio* | 900,000 | 1.50 |
| *Ctenopharyngodon idella* | 600,000 | 1.00 |
| *Osphronemus goramy* | 150,000 | 0.25 |
| *Anabas testudineus* | 150,000 | 0.25 |
| **TOTAL** | **60,000,000** | **100.00** |

**Sources:** *Nam and Leap (2007)*

## Case Study in Takeo and Kampong Speu Provinces, Cambodia

Takeo Province is located in the south-western part of Cambodia (**Fig. 2**) about 78 kilometers from Phnom Penh with a total area of 3,563 km$^2$ and embraces 97 communes and 1,118 villages (NCDD, 2012). Kampong Speu Province is located west of Phnom Penh with an area of 7,017 km$^2$. Takeo and Kampong Speu Provinces had been chosen for the study due to various reasons (Chin, 2013), such as the Provinces of Takeo and Kampung Speu support the country's large- and small-scale hatchery industry resulting from the efforts of FiA and NGOs. In addition, most fish seed producers have been operating in these provinces, where majority of the fish grow-out farms are also located. Although aquaculture in these areas is mostly managed by the private sector, it has received strong support from the government and other NGOs.


**Fig. 2.** Map of Cambodia showing the Provinces of Takeo and Kampong Speu

For the case study, Tram Kak District in Takeo Province and Basedth in Kampong Speu were taken as sample sites. Specifically, 23 fish hatchery operators (Tram Kak: 19; Basedth: 4) and 60 grow-out farmers (Tram Kak: 30; Basedth: 30) were chosen as the study's respondents (Chin, 2013). As shown in **Table 2**, there are 37 hatchery units in Takeo Province and 24 in Kampong Speu while there are 19,146 units of culture ponds, 12 culture cages, and 58 units of community refuge ponds in Takeo; and 1,824 culture ponds and 173 units of community refuge ponds in Kampong Speu.

**Fish seed production**

Although the country's fish seed production is mostly a small-scale activity considering the availability of water and limited nursing pond size as a result from small land holdings, most hatchery operators use adequate and up-to-date practices and facilities, and are well organized and flexible. However, inadequate skills in broodstock management as well as poor water quality, predation and drought had constrained them from efficiently and effectively operating their facilities. Despite these limitations, local fish seed producers continue to play a significant role in supplying fish seeds to aquaculture operations at local, provincial and even at national levels.

In the beginning, poor survival of fish seeds in ponds had discouraged fish farmers from buying locally-produced seeds. The high demand for fish seeds when many farmers joined the bandwagon of fish culture had prompted some seed producers to sell small-size fish seeds to fish farmers. Also, some farmers coming from distant places agree to buy fish seeds irrespective of size since they did not want to go back to their fishponds without the much needed fish seeds. As brokers for collecting fish seeds from hatchery producers and selling these to fish farmers, some nursery operators do not nurse the seeds for an adequate length of time. At this stage, the hapa nursing technology was adopted in Cambodia while extension support was improved to educate farmers on the need to either stock big size seeds or nurse fish seeds until reaching the appropriate size for stocking (Nam and Haing, 2007).

The socio-economic profile of fish seed producers in Takeo and Kampong Speu Provinces (**Table 4**) showed high proportion of men involved in fish seed production, *i.e.* 17 out of 19 producers in Takeo and three out of four in Kampong Speu, because of the manual labor required in fish hatchery operations (Chin, 2013). The case study also suggested that women provide active participation in the hatchery activities, especially in preparing the hormones and chemicals needed for breeding, taking care of the fish larvae, monitoring the quality of hatchery water, and marketing of the fry/fingerlings. The average age of the respondents at 48 years old, is considered mature enough to manage fish seed production activities. Moreover, their adequate educational background is essential in fish hatchery operations as they are able to absorb and adapt new knowledge and technologies necessary to improve their operations, as well as negotiate fairly with fish farmers during market transactions. Thus, most of the fish hatchery operators had received training on good fish hatchery management provided by FiA, including market sourcing and channeling their produce.

The average family size of hatchery operators at four (4) persons enabled most operators to avail of free labor from family members, cutting on labor costs. However, the average land holding of 0.6-1.0 ha/family limited the farmers' efforts to expand their ventures and continuously supply the demand for fish seeds in view of less number of

nursing and broodstock ponds, and smaller water reservoirs for keeping water used in breeding and hatchery operations. The main occupation of most farmers was producing fish seeds but some were also involved in different activities to earn additional income for their families' needs. Some fish farmers were also engaged in rice farming (50% from Takeo and 100% from Kampong Speu), which is the backbone of Cambodia's agricultural sector as rice is the country's staple food.

**Freshwater fish culture**

Fish grow-out farmers in Takeo and Kampong Speu Provinces (**Table 4**) were also mostly men, *i.e.* 83% in Takeo and 90% in Kampong Speu, in view of the manual labor required in fish grow-out operations (Chin, 2013), although both men and women contribute significant amounts of time to fish culture activities. While the youngest fish farmer was 26 years old and the oldest 72 years old, age should not be a criterion in fish culture although farmers should start from adult age to be able to carry out the laborious activities in small-scale fish culture operations. Some fish farmers were also engaged in other activities to earn additional income for their families' needs. Thus, most of the fish farmers reported that their sources of income come not only from on-farm but also from off-farm activities such as rice and vegetable farming, among others.

Fish farmers in Takeo and Kampong Speu Provinces started to culture fish in 2000 and most of them culture three species of carps, especially the common carp. Recently however, many fish farmers prefer to culture the silver barb because of the availability of adequate amount of fingerlings to supply their requirements. Since silver barb is an indigenous species in the Mekong River, its culture has been promoted by the FiA and MRC. Moreover, this species is also more suitable in pond culture because of its fast growth rate and high survival rate, and many consumers prefer this species for family consumption.

Generally, the fish farmers have good knowledge and experience in aquaculture operations. With suitable pond areas, fish farmers practice good pond preparation and fertilization, appropriate stocking density, feeding and pond management, and harvesting methods, and thus, get considerable yield. Although aquaculture could offer important long-term potential for Cambodia, the country's current production remains low relying essentially on small-scale pond operations. Nonetheless, in order to maintain the pro-poor focus on growth improvement, interventions are necessary to support small-scale fish farmers which could come in the form of capacity building, such as conducting training courses to enhance their skills and to some extent, providing them some inputs (*e.g.* fingerlings).

**Table 4.** Basic socio-economic data of respondents (Chin, 2013)

| Categories | Takeo | Kampong Speu | Total |
|---|---|---|---|
| *Fish seed producers **(n)*** | ***19*** | ***4*** | ***23*** |
| Gender (**% male**) | 90 | 75 | 91 |
| Age (%): | | | |
| ave = 48 years old | | | |
| 24-40 years old | 26 | 25 | 26 |
| 41-50 years old | 26 | 0 | 26 |
| 51-68 years old | 47 | 75 | 52 |
| Educational attainment (%) | | | |
| Primary school | - | - | 30 |
| Secondary school | - | - | 65 |
| Family size (%): | | | |
| ave = 4 members | | | |
| 2-3 members | 58 | 75 | 61 |
| 4-5 members | 37 | - | 30 |
| Land holdings (%): maximum = 2.0 ha | | | |
| Small (0.3-0.5 ha) | 26 | 25 | 26 |
| Medium (0.6-1.0 ha) | 38 | 50 | 38 |
| Large (1.1-2.0 ha) | 26 | 25 | 26 |
| Alternative occupations (%) | | | |
| Rice farming | 59 | 100 | 65 |
| Employment with Government | 21 | 0 | 35 |
| Annual income from seed production (%) (1USD = 4000 KHR) | | | |
| 1.000-10.000 million KHR | 63 | 75 | 65 |
| 10.001-20.000 million KHR | 11 | 0 | 9 |
| 20.001-80.000 million KHR | 26 | 25 | 26 |
| Fish consumption (%): ave = 272 kg/family/year | | | |
| 83-100 kg/family/year | 16 | 25 | 17 |
| 101-300 kg/family/year | 63 | 25 | 57 |
| 301-600 kg/family/year | 21 | 50 | 26 |

**Table 4.** Basic socio-economic data of respondents (Chin, 2013) (Cont'd)

| Categories | Takeo | Kampong Speu | Total |
|---|---|---|---|
| *Freshwater fish growers/ farmers **(n)*** | ***30*** | ***30*** | ***60*** |
| Gender (**% male**) | 83 | 90 | 87 |
| Age (%): ave = 48 years old | | | |
| 26-45 years old | 47 | 40 | 43 |
| 46-60 years old | 50 | 37 | 43 |
| 61-72 years old | 3 | 23 | 14 |
| Educational attainment (%) | | | |
| Primary school | - | - | 53 |
| Secondary school | - | - | 30 |
| Alternative occupations (%) | | | |
| Rice farming | 97 | 100 | 98 |
| Teaching | 3 | 0 | 2 |
| Annual income (%) from fish grow-out activities (1USD = 4000 KHR) | | | |
| 0.400-6.000 million KHR | 71 | 50 | 67 |
| 6.001-10.000 million KHR | 14 | 50 | 19 |
| Fish consumption (%): ave = 148 kg/family/year | | | |
| 100-140 kg/family/year | 33 | 33 | 50 |
| 141-240 kg/family/year | 54 | 67 | 43 |
| 241-360 kg/family/year | 13 | 0 | 7 |

## Relationship between Fish Seed Producers and Grow-out Farmers

According to many fish farmers from both provinces, their partnership with local seed producers which had substantially improved led to honest transactions in supplying sufficient quantity of good quality fish seeds so that they no longer use imported fish seeds for their fishpond operations. The characteristics of locally-produced fish seeds which farmers consider as indicators for good quality include good shape, bright color, fast growth rate, disease resistance, high survival rate, and easy to feed. In an impact survey conducted in 2009, the results indicated that all fish seeds required by the country's fish farmers had been supplied by local fish seed producers. Meanwhile, some public hatcheries have also been producing other species such as *Pangasius* spp. or walking catfish (Viseth, pers.comm. 2012) as this shift could provide them more income for operations.

While the amount of fish seeds produced locally by village hatcheries had significantly increased in both areas considerably meeting the demand of local fish farmers (FAIEX, 2009), the Government should encourage public hatcheries to consider transferring new technologies and knowledge (*e.g.* breeding of indigenous species) to private or farmers' hatcheries to increase their fish seeds production. Farmers' hatcheries should play the most important role of producing good quality fish seeds to supply the required inputs of local fish farmers in the future, more particularly, supplying locally-produced fish seeds of indigenous species. This would help reduce the negative impacts of exotic fish species on wild fish species due to accidental escape. This necessitates that locally-produced fish seeds should be made more available throughout the country by fish seed producers who have been adequately trained and received support from the FiA. This way, fish farmers would have more confidence to stock locally-produced fish seeds in their ponds.

An average demand of fish seeds is about 1,750 per family per year. Indigenous species (silver barb) is the most popular fish seeds especially for polyculture, of which about 49% is distributed nationwide compared with the other three species such as common carp, silver carp and other species (rohu, tilapia and mrigal). The high proportion of silver barb is influenced by a national regulation that encourages the culture of indigenous aquatic species in Cambodia. As a result of this development, fish farmers now do not utilize imported fish seeds for their pond culture unlike before when many fish farmers were reported to have been importing fish seeds for their ponds. The main reason of fish farmers for avoiding imported fish seeds is poor quality, since many farmers have encountered many problems that came with imported fish seeds, such as slow growth rate and seeds are more adapted to artificial feeds (pellet feeds) which are unavailable and expensive in rural areas.

In addition, the Government's intensified promotion of the use of locally-produced fish seeds gave fish farmers more advantages such as: healthy stocks; uniformity in size and age; fast growth rate; high survival rate and disease resistance. The other advantages are accessibility of local feeds as the stocks could be given such feeds as rice bran, kitchen wastes, vegetables, duckweed, termites, broken rice, and others; good price, and low environmental impacts. More particularly, training on responsible fish culture is also provided by fish seed producers before a fish farmer could start embarking on fish culture operations.

Freshwater fishponds in Kampong Speu, Cambodia

These factors contribute to the fish farmers' choice of locally-produced fish seeds over the imported ones. Such mutual relationship between fish seed producers and grow-out operators is therefore expected to contribute to the sustainable development of freshwater aquaculture in Cambodia.

## Recommendations and Way Forward

A major constraint of small-scale aquaculture dovetails to the technical and environmental aspects. Thus, fish seed producers in both provinces consider proper broodstock management as a priority that should be given more focus by the Government. Broodstocks that could give good quality and quantity of seeds should be promoted by the government including those that could withstand poor water quality conditions during the dry season, low water supply and drought, high temperature, limited nursing space, and predation. The market for locally-produced fish seeds could be increased by developing channels to middlemen rather than through growers, NGOs or government.

Furthermore, plans should be developed to support hatchery development in areas where water is abundant all year round, which is a general constraint in fish seed production activities. Considering that the profiles of the fish seed producers and fish grow-out farmers in Takeo and Kampong Speu Provinces are good, particularly in terms of education, production capacity and incomes, their relationship should be enhanced in order that the current one-one cooperation is sustained. Since fish seed producers get higher income and receive higher education than fish grow-out farmers, the former should be trained on the modern techniques of fish culture from hatchery to grow-out, and allowed to continue disseminating the techniques they learn from such training to fish grow-out farmers. Moreover, fish seed producers consume higher amount of fish than fish grow-out farmers, which could be due to the reliance of fish seed producers on fish that they also produce, while fish grow-out farmers who are engaged in rice farming and other activities consume more agriculture staples. Nevertheless, since fish seed producers and grow-out farmers have sufficient resources, both stakeholders should be encouraged to enhance their capability in undertaking fish culture activities, as this could provide them new and better alternative incomes.

There is now an established tradition of fish seed production in the two study areas despite drought and limited water infrastructure. Most producers are successful in producing fish seeds during the seasonal breeding season (end of February to mid of October), depending on the amount of rainfall. The fish seeds produced show good quality in terms of shape, bright color, uniformity of size and age, fast growth rate, disease resistance, healthy, high survival rate, low environmental impacts, and easy to feed especially with locally available feeds. Nonetheless, some barriers such as the lack of water should be addressed by the government. Moreover, the fish producers' capacity in broodstock management should also be enhanced as their knowledge and skills are still limited. The distribution of fish fingerlings from both provinces is already widespread reaching the northwest provinces of Cambodia, which are close to Thailand, up to the northeast provinces, near the border with Vietnam.

Fish grow-out farmers have adequate knowledge in aquaculture practices, after attending fish culture training courses provided by FiA and fish seed producers. With suitable pond areas, good practices in pond preparation, and fertilization, stocking density, feeding, pond management, and harvesting, fish farmers are now getting fair quantity of fish produce. Fish seed production enterprise is also becoming a profitable business in these two provinces. Rural farmers have expressed satisfaction with government and NGOs for their technical supports, and their desires to expand operations in the future. Locally produced fish seeds are available for existing fish farmers, but new farmers who are still starting into fish culture could avail of their required inputs through the provincial fish seed production network. Supply of imported fish seeds had collapsed as the seeds could not compete anymore with the locally-produced fish seeds as it used to enjoy before. Fish seed production in the country could still be increased, *i.e.* by increasing surface area or enhancing the yield from each hatchery.

Considering that land is a constraint as it is quite impossible for poor farmers to acquire more areas of lands, studies should be conducted on improving production efficiency that produces better yields per area and ensures that costs of production would not exceed the value of fish produce, such as improving water quality management, increasing nursery areas and improving the quality of broodstocks. In addition, the market network of locally-produced fish seeds should be expanded while the services of middlemen could also be considered. Nursery management should also be improved to increase the survival of fry after breeding in hatcheries. The combination of these approaches could result in dramatic increase of total production not only in terms of fish seeds but also in marketable-size fish. Furthermore, sustaining the partnership between fish seed producers and fish grow-out farmers which presently exhibits a one-one cooperation and not competition, should be given utmost attention in order to maintain a healthy environment for sustainable aquaculture development in the country.

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### About the Author


**Ms. Chin Leakhena** is Vice Head of Fish Diseases and Genetic Division, Fisheries Administration, Ministry of Agriculture, Forestry and Fishery, Cambodia. She is a member of the 2014 Regional Fisheries Policy Network for Cambodia, based at the SEAFDEC Secretariat in Bangkok, Thailand.

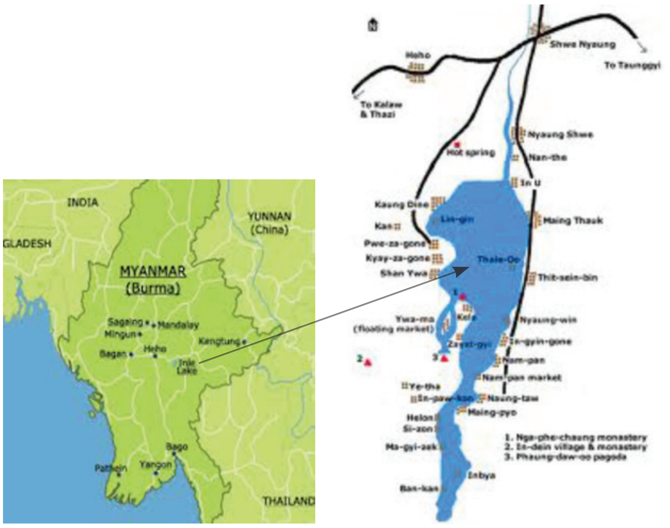
# Preserving a Critical Fishery Resource in Inle Lake, Myanmar for Sustainable Fisheries and Food Security

*Myo Min Hlaing*

Inle carp (*Cyprinus intha*) is a bottom dweller species of carps which is endemic in Lake Inle of Myanmar. This species of carp is being driven to near extinction due to overfishing and environmental degradation of its natural habitat. Lake Inle is the second largest natural inland water body in Myanmar. Situated in Shan State in the northeastern part of the country, Lake Inle has an area of about 116 km$^2$ and sits in a tropical monsoonal area with diverse species of flora and fauna. Recently, the Lake has suffered environmental degradation due to deforestation and agro-chemical pollution, a situation that affects not only the Inle carp that inhabits the Lake due to its degrading water quality but also the Intha fishers who depend on Lake Inle and Inle carp fisheries for their livelihoods.

Inle carp (*Cyprinus intha*) is a Cyprinid fish commonly found in Lake Inle and an endemic species in Myanmar. In 2011, the IUCN Red List declared the Inle carp as endangered as it had been impacted by the introduction of some *Cyprinus* species in the Lake. *C. intha* inhabits the shallow zone of the Lake, especially in areas with dense submerged vegetation and muddy with high organic bottom. Spawning of this species usually takes place in waters with temperature ranging from 24°C to 26°C, between November and March.

The inland waters of Myanmar include natural inland and seasonal water bodies as well as freshwater fishponds that are being tapped for fisheries, which has been playing a vital role in the cultural and socio-economic advancement of the country. These natural inland water bodies include riverine and estuarine systems, such as the Ayeyarwady (also known as Irrawaddy) measuring about 2,150 km long, Chindwin (844 km), Sittaung (503 km), and Thanlwin (2,400 km long) Rivers (Welcomme, 1985); and lakes such as Lake Inya, Lake Kandawgi, Lake Indawgi, and Lake Inle, among others.




*Clockwise:* Map of Myanmar showing Lake Inle, and intha fishers' technique of rowing boats in Lake Inle with a unique motion that has become a symbol of the local intha tribe

Inle carp, *Cyprinus intha* (below) and common carp (above)

A highland water body, Lake Inle is the second largest lake in Myanmar with a surface area of about 116 km$^2$ and an altitude of 880 m, with average water depth of about 2 m. Flanked by high mountains, the Lake is host to a number of endemic aquatic species including more than 20 species of snails and nine species of fish that are not found elsewhere in the world. The people of Lake Inle, called *inthas*, use small boats for transportation and fishing with a unique style of propelling by standing on the stern of the boat on one leg and the other leg secured on a single oar as they balance the boat while fishing or traversing the Lake's still waters. This technique enables rowers to see and elude floating vegetations on the Lake including floating gardens that are anchored in the Lake's bottom with bamboo poles, as well as see the lakeshores beyond the reeds and other growing vegetations.

On Lake Inle, the *inthas* have a unique practice of raising tomatoes and squash as well as growing cut flowers. Known as floating gardens, these are long strips of floating structures formed by tying together tangled water hyacinth, weeds and reeds that accumulate on the shores of the Lake, and secured at the bed of the lake using long bamboo poles. A form of hydroponic agriculture, the floating gardens primarily produce tomatoes which the *inthas* sell in local markets. Moreover, the *inthas* are also famous for weaving fabrics utilizing lotus and water hyacinth fibers believed to be fine, luxurious and silky. As major alternative livelihoods for intha fishers, these also serve as their means of maximizing the resources of Lake Inle. Moreover, the *inthas* also build their houses above the lake waters on stilts possibly exacerbating the pollution and siltation of the Lake.

During the past decades, Lake Inle has been going through severe environmental degradation brought about by siltation and pollution. Siddle *et al*. (2007) cited that between 1886 and 1948, the Lake had shrunk by 15% while its open water surface area had been reduced by 32% between 1935 and 2000. One of the major causes of the decreasing area and surface water is deforestation in the mountains flanking the Lake as well as along the banks, and agricultural encroachment and the practice of shifting cultivation on the lakeshores (Su and Jassby, 2000). Within the Lake, cultivation of tomatoes and to certain extent squash and cut flowers in floating gardens which the *inthas* have been practicing for a long time (Siddle *et al*., 2007) has impacted the water quality of the Lake due to excessive use of agro-chemicals (Akaishi *et al*., 2006).

Floating garden *(above)* and *inthas* fishing in Lake Inle using the traditional gear Inle saung *(below)*

## Fisheries Production of Myanmar

Inland fisheries that include capture fisheries and freshwater aquaculture are very important for food security and economy of Myanmar. As shown in **Table 1**, the country has seen much progress in terms of inland fisheries development with inland capture fisheries accounting for an annual average of 26% and freshwater aquaculture by about 19% of the country's total fisheries production from all sectors during the five-year period from 2007 to 2011. Moreover, the country contributed 44% to the total inland capture fisheries of Southeast Asia in 2011, 13% to the region's total production from freshwater aquaculture in the same year, and its total production from all sectors contributed about 12% to the region's total fisheries production. The main species produced from inland capture fisheries (SEAFDEC, 2013) is freshwater gobies although the species were not identified, mostly captured from rivers (83%) and other inland water bodies (17%). For freshwater aquaculture, the most important species is *Labeo rohita*

**Table 1.** Five-Year Fisheries Production of Myanmar (in metric tons (MT))

| Myanmar Production: | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|
| **Inland Capture Fisheries** | **717,640** | **814,740** | **899,430** | **1,002,430** | **1,163,159** |
| Freshwater Aquaculture | 556,354 | 605,552 | 670,773 | 772,396 | 761,697 |
| Total Fisheries Production | 2,808,037 | 3,147,605 | 3,491,103 | 3,901,979 | 4,149,799 |
| **Southeast Asian Production:** | | | | | |
| **Inland Capture Fisheries** | **2,008,301** | **2,329,524** | **2,397,273** | **2,377,253** | **2,641,094** |
| Total Freshwater Aquaculture | 3,292,292 | 4,345,762 | 4,739,861 | 3,097,970 | 6,071,294 |
| Total Fisheries Production | 25,302,870 | 27,207,826 | 28,917,096 | 31,438,435 | 33,487,689 |

***Sources:*** *Fishery Statistical Bulletin of Southeast Asia (SEAFDEC, 2010a, 2010b, 2011, 2012, 2013)* (rohu) accounting for about 70% of the total production from freshwater aquaculture in 2011 (SEAFDEC, 2013) followed by *Catla catla*, tilapia, mrigal carp (*Cirrhinus mrigala*), grass carp (*Ctenopharyngodon idella*), bighead carp, *Pangasius* spp., and others contributing the remaining 30%. Inle carp (*Cyprinus intha*, Annadale 1918), which is endemic to Lake Inle, is a staple of the local diet of the *inthas*. Reported to be endangered and is now in the IUCN Red List Category, this native species has been affected by overfishing, as well as increased sedimentation and euthrophication from expanding agriculture activities in and around the shores of the Lake. In addition, this species may have also been impacted by competition and hybridization of the common carp *Cyprinus carpio*, recently introduced in the Lake (Vidthayanon, 2013).

*Intha* fishers depend on Lake Inle for their livelihood using several types of fishing gear such as set gill net, hook and line, Inle *saung* and fish trap. Although the main fish species caught by gill net are tilapia, featherbacks and snakeheads, some local species including the Inle carp (*Cyprinus intha*) are also caught resulting in the depletion of their stocks year by year. Meanwhile, the most important species for freshwater aquaculture are major carps including the Indian carps, namely: rohu (*Labeo rohita*), *Catla catla*, and *Cirrhinus mrigala*.

Some introduced species of common carp (*Cyprinus carpio*), Chinese grass carp (*Ctenopharyngodon idella*) and silver carp (*Hypophthalmichthys molitix*) are also being cultured in freshwater environments of the country. Fish seed production is one of the most important aspects in the country's freshwater aquaculture since fish farmers have been using fish seeds that are mostly collected from natural sources (Myo, 2013). An age-old practice in the country, collecting fish seeds from the wild limits the availability of pure fish seeds since the collected seeds generally comprise mixed stocks together with both desirable and undesirable fish species, and separating the desirable seeds from the mixed stock is a gigantic task. In order to overcome these problems, induced breeding of desired species especially the endangered species, has been promoted in the country not only to supply the demands of the freshwater aquaculture industry but also to conserve endangered aquatic species by enhancing their stocks, especially in Lake Inle for sustainable fisheries and food security of the local people, the *inthas*.

## Breeding and Culture of the Inle Carp

Okamoto (2012) reviewed the capacity of *intha* fishers to adapt and cope with the current deteriorating Inle carp resources in Lake Inle of Myanmar. Based on the framework developed by Agrawal (2008) which classifies possible adaptation and coping strategies into mobility, storage, diversity, community pooling, and market change, Okamoto (2012) cited that *intha* fishers may not be able to adopt mobility because of the decreasing catch of Inle carp from the Lake while storage is also not feasible since the *inthas* do no process the fish as these are sold fresh in the market. Although diversification which includes culturing the fish among others could be an option, stability of fish culture should be ensured in order that this could provide supplementary incomes for the *inthas*, while the issues and constraints in the culture of Inle carp should also be addressed. Another option to sustain the Inle carp resources is by controlling the fishing periods but this could be difficult to enforce as *intha* fishers continue to fish throughout the year in order to survive. Similarly, community pooling and market change would not be possible options considering the present local economy in the Lake's fishing communities.

In an attempt to promote the breeding and culture of Inle carp for the conservation of this important resource and for providing alternative livelihoods to intha fishers, Myo (2013) conducted a case study on the development of seed production techniques for Inle carp which could be disseminated to grow-out fish farmers in Myanmar. Such study was initiated with the main goal of preserving a critical fishery resource in Myanmar's Lake Inle, *i.e.* the Inle carp *Cyprinus intha*, for sustainable fisheries and food security of the local people.

### Seed Production of Inle Carp

Currently, the seed production technique for Inle carp being promoted in the country follows the hypophysation method or the practice of injecting crude fish pituitary extracts into breeders. Since the 1970s, fish breeding by pituitary gland extraction has been considered an effective and dependable way of obtaining pure seeds of cultivable fishes and is a simple practice that can be adopted by most fish famers in Myanmar. Since the common carp, *Cyprinus carpio* is a perennial breeder and its mature individuals could be obtained almost all year round for collection of pituitary glands, this carp species has therefore been used for pituitary gland extractions. The most suitable time for collecting pituitary glands of common carps is during May to July, when majority of carps attain advanced stages of maturity. If the collected pituitary glands are not meant for immediate use these must be preserved to prevent immediate enzymatic action by using absolute alcohol or acetone and freezing. Preservation of fish pituitary glands in absolute alcohol is most preferred because this makes seed production technique through hypophysation method easily transferrable to fish farmers in rural communities of Myanmar. Through this breeding technique, seeds of fish species required by local fish farmers could be made available for their culture operations, as in the case of the Inle carp for food security and poverty alleviation in fisheries communities along Lake Inle.

Generally, Myanmar could be considered as a carp country, where carps alone contribute 85% of the country's total production from aquaculture. In fact, the successful induced breeding of major carps through hypophysation technique was achieved in Myanmar in early 1960s (Fishery Statistics of Myanmar, 2009-2010). Thereafter, several inducing agents have replaced the fish pituitary glands extractions for induced breeding, especially those that allow fishes to reproduce for long-lasting periods on their own through their seasonal or continuous reproductive cycle. Nevertheless, various methods of induced breeding of carps are being extensively adopted in the country, to adequately supply the fish seed requirements of many fish farmers who had been dependent earlier on natural fish seeds collected from the wild, the quantity of which has already been severely decreasing through the years.

*Cyprinus intha* inhabits in the shallow zone of Lake Inle, and spawning usually takes place in waters with temperature that range from 24°C to 26°C between November and March (Myo, 2013). Results of the study of Aye (2007) on the Gonadosomatic Index (GSI) of *C. intha* from November 2006 to April 2007 showed that the highest GSI value was between November 2006 and January 2007, while the lowest GSI value was attained during December 2006 and March 2007. According to Smith (2004), peaks of GSI value occur prior to spawning (pre-spawning) and spawning is evidenced by sharp decline in GSI value.

For oviparous fishes, the extruded eggs could be demersal (on the bottom) or pelagic (above the bottom, and often at or near the surface). Eggs produced by demersal egg spawners are heavier than the surrounding water and develop on the bottom or attached to the substrate or float loosely on the bottom. Being demersal in nature, eggs of *C. intha* have been observed at the roots of water hyacinth or float loosely at the bottom. The embryonic development of *C. intha* is divided into six periods: zygote, cleavage, blastula, gastrula, segmentation, and pharyngula and hatching period (Myo, 2013). Hatching occurs 71-72 hours after spawning, and the newly hatched larva is 5.21 ± 0.04 mm in length surrounding the yolk sac. According to Kimmel *et al*. (1995), Stroban *et al*. (1992, 1995) and Steven *et al*. (1996, 1998) cited in Nica *et al*. (2012), carp embryonic development is more or less similar in nature.

In the case study of Myo (2013), the larvae reached the fry stage after 8 days of hatching. After four weeks, the fry increased in length to 18-23 mm, with distinct dorsal, anal, ventral and pectoral fin and the body entirely covered by scales and appeared similar to an adult. The result also implies that hatching and larval development occurred in water temperatures of 24°C-26°C, which correspond to the normal water temperature in Lake Inle. These findings were the same as Ghosh *et al*. (2012) where Koi carp eggs would hatch after 72-73 hours at water temperatures of 26°C-28°C. Kuo *et al*. (1973) and Liao (1975) also reported that the incubation period of carp eggs and larval development would depend largely on water quality parameters such as salinity and temperature.

**Culture of Inle Carp in Freshwater Ponds**

Fish cultured in freshwater ponds in Myanmar generally comprises the common carps, Indian carps and Chinese carps. These species are characterized by their fast growth and with good adaptability in confined waters. Aquaculture, not only in commercial-scale but also in small-scale is an important protein source for rural communities in the country. Freshwater aquaculture in Myanmar started in 1954 using introduced species such as tilapia, gouramy and common carps. Many attempts had been made to culture Inle carp, *Cyprinus intha* in fishponds near the Lake Inle to preserve this endemic species which has been declared as endangered. Nevertheless, sustainable aquaculture of Inle carp should start with good seed production technique so that fish farmers would not have to rely on seeds from the Lake (Myo, 2013). In this aspect, the technique of producing the seeds in hapa nets was promoted as this is easy to transfer to fish farmers including fish seed producers. In the case study, Myo (2013) also promoted the polyculture of Inle carp with other carp species considering that this species is bottom dweller and thus, surface and column feeders could be cultured at the same time. Specifically, since freshwater ponds usually produce variety of food organisms in different layers of the water, stocking various species that have complementary feeding habits or that feed in different zones could therefore, be done in a polyculture system to efficiently utilize space and available food and increase total fish production. In the global scenario, cyprinids such as *Labeo rohita*, *Catla catla* and *Cyprinus carpio* are the main species popularly polycultured since *Catla catla* is a surface feeder, *Labeo rohita* is a column feeder, and *Cyprinus carpio* is a bottom feeder fish.

## Issues, Concerns and Recommendations

During the last two decades, Inle carp, *Cyprinus intha* (Annandale 1918) has played an important role in supplying food fish to the local people inhabiting the lakeshores of Lake Inle in Nyaung Shwe Township in Southern Shan State of Myanmar. The high demand for Inle carp by the local people resulted in overfishing which eventually led to the gradual decline of the species in various parts of the Lake. Local fish farmers who are not much familiar with the culture of *C. intha*, had not attempted any culture operation in fishponds in view of their inadequate knowledge of breeding and feeding techniques, while seeds from the wild had also become very scarce. Although many researchers had attempted to develop seed production techniques for *C. intha*, these efforts have not been disseminated considerably to the local fish farmers. Therefore, in order to address insufficient data and information on this species including its culture potentials, concerned agencies should try to promote breeding techniques, including larval culture techniques, larval rearing, and so on. Furthermore, investigation on stocking density of fingerlings in fishponds and release of fish seeds for the purpose of conservation and sustainable fisheries of this important resource in Lake Inle, should also be promoted.

Based on the results of the experiments in ponds, Myo (2013) suggested that *C. intha* could be cultured in fishponds for both breeding and commercial purpose. Bagenal and Tesch (1971) cited in Sedagnat (2013) stated that the parameters of the fish, length and weight relationship are affected by a series of factors including season, habitat, gonad maturity, sex, diet, stomach fullness, health and preservation techniques. These aspects should also be considered during the conduct of R&D of this species. The concept of polyculture of fish is based on concept of total utilization of different trophic and spatial niches of a pond in order to obtain maximum fish production per unit area. Based on the case study, the suitable combination of the surface feeder *Catla catla* and the column feeder *Labeo rohita* could be stocked in a pond with the bottom feeder *Cyprinus intha* in a polyculture system.

The results of the case study (Myo, 2013) also revealed that the highest fish production was observed when organic fertilizer (cow manure) was used and supplementary feeds such as peanut oil cake, rice bran and maize flour were given along with fish meal, agreeing with the findings of Mahboob and Sheri (1997) that higher fish production was obtained when broiler droppings were used compared to the use of NPK fertilizer in culturing major species of carps. As recommended by Yadava and Garg (1992), using organic manure as fertilizer in ponds would provide economic benefits to fish farmers as it could reduce operations cost by 50% from using inorganic fertilizers and supplementary feeds. Since supplementary feeding is known to increase the carrying capacity of culture systems and can enhance fish production by several folds (Jhingran, 1995), concerned agencies should enhance its R&D activities on the use of locally-produced feeds using locally-available materials in order to reduce costs in fishpond operations. Polyculture of *C. intha* with other carp species should also be promoted with the practice of using organic fertilizers and supplementary feeds that are available and cheap in localities that surround Lake Inle.

Furthermore, the sustainable and intensified production of *Cyprinus intha* fingerlings should also be considered for culture-based fisheries, taking into account the fact that survival rate of fingerlings released to the wild could decline during the culture period, and consequently, most fish farmers could not provide adequate number of fingerlings for culture-based fisheries. In this regard, responsible seed production of *C. intha* should be promoted as an industry near the Lake Inle, while maintaining the habitat of *C. intha* to be environment-friendly for the species to thrive successfully should be advocated. The need to re-stock the Lake with hatchery-produced *C. intha* should also be considered otherwise, Myanmar's natural assets in Lake Inle, the endemic Inle carp might completely disappear and eventually lead to the extinction of this important commodity in the Lake.

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### About the Author

**Dr. Myo Min Hlaing** is an Assistant Director of the Department of Fisheries of Myanmar. He is a member of the 2014 Regional Fisheries Policy Network for Myanmar, based at the SEAFDEC Secretariat in Bangkok, Thailand.

# Tilapia Genetic R&D in the Philippines:
## Challenges and Prospects for Future Development

*June Feliciano F. Ordoñez, Mudjekeewis D. Santos* and *Melchor M. Tayamen*

Tilapias (*Oreochromis* spp.) are important aquaculture commodities that have been constantly studied in aquaculture genetic research and development (R&D). Specifically, genetic technologies including sex and chromosome-set manipulations, DNA markers, and transgenesis have created practical applications in tilapia culture. Recent advances in computing and sequencing technologies have facilitated the genetic and genomic studies in tilapia, making this commodity one of the most studied aquaculture species with robust available genomic-scale data. After dedicating efforts to the implementation of breeding programs that aim to improve the performance of farmed tilapia stocks, the Philippine tilapia aquaculture industry had rapidly developed and made substantial impacts on the country's total fish production. Success in such endeavors has changed the status of the country's tilapia aquaculture industry into a more productive one, shifting the Philippine perspective of becoming a globally-competitive tilapia producer. Nevertheless, despite the success in producing novel strains of tilapia with improved qualities, the tilapia aquaculture industry of the Philippines still continues to face challenges particularly in the area of genetic R&D.

During the past decades, genetic technologies including sex and chromosome-set manipulations, genome mapping, DNA markers, transgenesis, and marker-assisted selection (MAS) have already found their way for new and practical applications in aquaculture. However, results of the application of these modern technologies, especially gene transfer and manipulation, and DNA marker technique, have not yet made much impact on the aquaculture industry. It is believed that verification of the former although holding much promise has been constrained by inadequate resources while the latter has allegedly led to not very positive effects, thus, its adoption has been restricted to certain extent (Hulata, 2001). Nonetheless, many genetic tools are now continuously being applied to the aquaculture of a wide range of commodities, *e.g.* salmon, trout, catfish, common carp, tilapia, and ornamental fishes.

Tilapia (*Oreochromis* spp.) is not only economically valuable but has also been considered scientifically important for research studies on aquaculture genetics from the classical selective breeding and hybridization to drafting its recently released whole genome sequence (*http://www.broadinstitute.org*). Through the traditional breeding programs of the Philippines, benefits from genetic applications in tilapia R&D including the development of various genetically improved tilapia species have been reaped. The country's project on Genetic Improvement of Farmed Tilapia (GIFT), the first selective breeding initiative launched in the Philippines, served as a starting point for tropical fish genetic improvement programs around the world (Gupta and Acosta, 2004) and was recognized as the first project to formulate a selective breeding program for *O. niloticus* (Eknath *et al*., 1993). The introduction of GIFT and other improved tilapia stocks to the aquaculture industry since 1998 resulted in the rapid boost of tilapia production not only in the Philippines (Toledo *et al*., 2009) but also in other Southeast Asian countries (**Table 1**). However, despite successes in genetic enhancement of tilapia, the country's efforts to apply modern tools and techniques such as DNA marker technology in tilapia genetic research continue to be insufficient.

**Table 1.** Tilapia production (in metric tons: MT) of Southeast Asia

| Southeast Asian countries | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|
| Brunei Darussalam | 50 | ... | ... | ... | 6 |
| Cambodia | 600 | 600 | ... | ... | ... |
| Indonesia | 95,699 | 97,085 | 328,831 | ... | 458,152 |
| Lao PDR | ... | ... | ... | ... | ... |
| Malaysia | 28,887 | 32,024 | 34,823 | 35,583 | 38,886 |
| Myanmar | 10,000 | 3,300 | 30,938 | 34,860 | 85,848 |
| Philippines | 190,043 | 228,748 | ... | 260,911 | 258,638 |
| Singapore | 5 | 3 | ... | ... | 40 |
| Thailand | 205,568 | 213,800 | 217,200 | 209,141 | 179,355 |
| Vietnam | ... | ... | 50,000 | ... | ... |
| **TOTAL** | **530,852** | **575,560** | **661,792** | **540,495** | **1,020,925** |

**Note:** Some countries were unable to provide updated data during the reporting periods (SEAFDEC, 2009-2012)

## Genetic Applications in Tilapia Aquaculture

Various commodities have been used in carrying out genetic improvement of stocks for the aquaculture industry. Specifically for tilapia, selective breeding, hybridization, and chromosome set manipulation, also known as traditional genetic improvement techniques have been adopted to improve the stocks (McAndrew and Napier, 2011). Later, the application of wide range of techniques such as the molecular-based approaches (*e.g.* genetic markers, genetic mapping and functional genomics, transgenesis) followed suit not only for tilapia but also for other aquatic organisms.

**Genetic markers for monitoring and management**

In aquaculture, good quality seeds are results of proper broodstock selection and management while poor stock management practices are potential causes of reduced stocks performance (Eknath *et al*., 1991; Hulata *et al*., 1986; Macaranas *et al*., 1995). Therefore, in order to increase production, improvement of stocks is necessary including sound inferences on the monitoring and management processes that are not solely based on selective breeding and the culture methods used, but also on the genetic characteristics of the stocks. The use of DNA markers as genetic tools for aquaculture monitoring and management have become a significant trend in tilapia culture operations. While markers and microsatellites have seen notable impacts in genetic aquaculture research, markers have also been very effective in addressing a wide array of concerns in tilapia aquaculture and are used to provide more accurate information on the genetic diversity of natural stocks (Agnese *et al*., 1997).

**Genetic mapping and functional genomics**

With recent advances in computational and sequencing technology, assembly of large genomic resources for many aquatic organisms including non-model species had become easier and faster, making the required data readily available. From various sequencing innovations, tilapia has become one of the major aquaculture species with the most robust genomic-scale data available where genomes (genetic materials of an organism) had already been documented from karyotypes (chromosomes of a cell displayed in systematized and paired arrangement) of various tilapias down to their genome (Majumdar and McAndrew, 1986; Guyon *et al*., 2012). While several sets of genetic markers to determine the genetic linkage maps of tilapia had been charted, *e.g.* microsatellite-based linkage maps, the bacterial artificial chromosome (BAC)-based physical map of tilapia genome has also been generated (Katagiri *et al*., 2005). Such feat has significantly contributed to the establishment of more comprehensive genetic and physical maps of tilapia which became useful in subsequent genetic studies.

Recently, genomic data from tilapia had increased but studies focusing on genome scan for tilapia are presently very few. Nevertheless, it is apparent that next generation sequencing (NGS) technology is probably the most efficient method for identifying genetic markers (*e.g.* microsatellites and single-nucleotide polymorphisms (SNPs) and genetic linkage and physical map construction. Developing genetic and physical maps of tilapia also represent a valuable resource to support the identification and isolation of genes or quantitative trait loci (QTLs) which control the economically-important traits of the species for comparative genomic studies (*e.g.* genome evolution) and further interventions (*e.g.* marker-assisted selection (MAS)). Aside from growth and body weight-related markers, one of the interesting aspects in tilapia genetic mapping studies is the identification and mapping of markers and QTL alleles associated with sex-linkage (Ezaz *et al*., 2004; Shirak *et al*., 2006; Cnaani *et al*., 2008; Liu *et al*., 2013). These data have immediate uses for tracking sex-linked haplotypes in breeding programs aimed at controlling the sex of fingerlings for commercial production of monosex populations (Lee *et al*., 2004). Extensive mapping has also been carried out for the other commercially-important traits of tilapia such as cold and salt-tolerance.

Functional genomics has also been considered an important research area for aquaculture, and their applications include investigation of the relationship of somatic growth and different factors as reflected in the levels of expression of certain genes. This is useful for the development or rearing of strains with enhanced growth. In tilapia, Vera Cruz *et al*. (2006) established a positive correlation between the levels of hepatic insulin-like growth factor-I (IGF-I) and growth rate, suggesting that measurement of IGF-I could prove useful as a rapid and direct indicator of growth in tilapia. In addition, at optimum combination of temperature and dietary protein, enhanced growth rate and feed utilization could be attained from the increased expression of somatotropic genes including pituitary growth hormone (GH), hepatic growth-hormone receptor 1 (GHR1) and IGF-I mRNA (Qiang *et al*., 2012). Therefore, the levels of expression of somatotropic genes could be used to assess the growth of tilapia species.

**Transgenic tilapia**

Transgenesis is defined in textbooks as the introduction of exogenous gene or transgene to a living organism in order for it to acquire new property that could be transmitted to its offspring. The availability of fish gene sequences has made a remarkable impact in transgenesis of cultured fish species including tilapia, where much focus in transgenic research had been placed on the development of strains capable of accelerating growth as well as germ cell transplantation (Farlora *et al*., 2009) and turning into potential biofactories for valuable pharmaceutical products (Maclean *et al*., 2002), among others. Furthermore, generations of cold-resistant and saline-tolerant transgenic tilapia lines are also currently being developed through transgenesis (He *et al*., 2013). Although transgenic fish technology offers a promising contribution to aquaculture advancements, it still needs to be experimentally refined. Nevertheless, in order to improve the efficiency in producing transgenic tilapia, research studies have made focus on the application of different gene transfer techniques.

Guillen *et al*. (1999) conducted a study to address health risk concerns from consumption of transgenic tilapia, where transgenic hybrid *Oreochromis urolepis hornorum* that contained an expressed tilapia GH transgene were given to 22 persons for five (5) consecutive days, twice daily. After the evaluation, results showed that consumption of the transgenic tilapia showed no effect on any clinical or biochemical parameters consequently confirming that the fish GH is not bioactive in primates. However, there is still no authenticated release of transgenic fish for aquaculture because of difficulties in assessing the environmental risk of escapees if culture is made outside experimental laboratories (McAndrew and Napier, 2011). Therefore, sterility in transgenic fish has been used as a control measure to contain transgenic tilapia, especially when completely secured land-locked facilities are not available (Maclean *et al*., 2002) since transgenic technology could be exploited and thus, risks associated with rearing transgenic tilapia and genetically modified (GM) fish in general, could be minimized.

## Tilapia Genetic Research in the Philippines

In the Philippines, the culture of tilapia began in 1950s with the introduction of the Mozambique tilapia species (*Oreochromis mossambicus* Peters 1852), but culture of this so-called "wonder fish" failed to promote commercial production because of its unwanted characteristics such as early maturation resulting in overpopulation in fishponds, stunted growth, small size at harvest, becoming "pests" in brackishwater ponds, and unappealing dark color (Bolivar, 1993; Guerrero, 1994). This led to the launching of a research program at the Freshwater Aquaculture Center of the Central Luzon State University (FAC-CLSU) in the Philippines in 1974 on monosex male culture and sex reversal of females through hormone treatment of tilapia fry (Guerrero, 1994). This was the earliest genetic application to improve tilapia production in the country that also marked the emergence of a line of technologies for commercial tilapia production that were developed over the succeeding decades (Yosef, 2009).

In 1970s, different strains of Nile tilapia (*Oreochromis niloticus* L.) were introduced in the Philippines from various origins (Guerrero and Tayamen, 1988; Bolivar, 1993). These strains rapidly gained popularity with farmers and consumers because of better characteristics (*e.g.* lighter color, faster growth, and high tolerance to various environmental conditions) over the Mozambique tilapia. However, problems were encountered later on the culture of these species.

Early on, major constraints in tilapia culture (and tropical fishes in general) that confront many developing countries include inadequate supply of seeds and poor genetic quality of cultured stocks compared to the wild population because of inbreeding depression (Pullin and Capili, 1988; Eknath *et al*., 1993; Acosta *et al*., 2006). In fact, tilapia production began to decline in 1980s due to the deterioration of genetic quality of tilapia stocks that led to significant reduction in performance of farmed Nile tilapia. Thus, the public sector, national institutions and international organizations based in the Philippines initiated in 1986 several programs on selective breeding and development of other technologies for genetic improvement using the Nile tilapia (Bolivar, 1993; Acosta *et al*., 2006).

Various agencies in the Philippines embarked on R&D programs to improve tilapia strains for aquaculture through genetics and biotechnology to make the aquaculture industry of the Philippines more profitable and sustainable (DA-BAR, 2001), such as the Aquaculture Research Development and Extension Division of the Department of Agriculture-Bureau of Agricultural Research (DA-BAR) and the Philippine Council for Aquatic and Marine Research Development [(PCAMRD), now the Philippine Council for Agriculture and Aquatic Resources Research and Development (PCAARD)]. While the potentials for increased aquaculture production were seen through better farm management, it was deemed necessary to increase the supply to meet the demand, which could be achieved through the use of genetically improved breeds/strains. Therefore, several genetic techniques for stock enhancement have been applied to increase the country's global competitiveness in the production of tilapia and other aquatic commodities that could provide better quality of life for fish farmers and fisherfolk (Abella, 2006).

At present, tilapia is the second most important food fish for domestic consumption in the Philippines (Lopez *et al*., 2005; BFAR, 2010) after milkfish (*Chanos chanos* Forsskal 1775). This national scenario emanated from increased tilapia production brought about largely by various efforts in tilapia genetics R&D that resulted in significant advances in the genetic improvement specifically in Nile tilapia. While the main focus of most of early research studies was to improve growth performance (Eknath *et al*., 1993; Basiao *et al*., 1996; Bolivar and Newkirk, 2002; Tayamen *et al*., 2006), this had shifted later to initiatives that aimed to produce strains that would perform well in different culture environments such as in farms with low-temperature or high-saline levels (Romana-Eguia and Eguia, 1999; Tayamen *et al*., 2002; Rosario *et al*., 2004). Such tilapia breeding programs have not only led to the tremendous progress in terms of increased tilapia production in the Philippines but also highlighted the application of genetics for various aquaculture commodities in the country.

## Products of Tilapia Breeding Programs

In the Philippines, different tilapia strains were produced from the various breeding programs as shown in **Table 2**, through multi-institutional collaboration among government institutions, agencies and international organizations with funds coming from both national and international donor agencies (Abella, 2006). The various strains developed and generated from such programs, *i.e.* GIFT, FaST, YY-male and GMT, GET EXCEL, GST™, SST, Salt-tolerant strains (Molobicus and BEST), and Cold-tolerant, are described in **Box 1**.

**Table 2.** Genetic breeding programs carried out in the Philippines (Modified from Abella (2006) and Acosta (2009))

| Strain Developed | Research Project | Project Year | Implementing institutions | Donor(s)/Funding institution(s) | Significant Results | Producers | Commercial Distribution |
|---|---|---|---|---|---|---|---|
| FAC-selected Tilapia (FaST or "IDRC" strain) | Fish Genetics Project | 1986-1996 | FAC-CLSU | International Development Research Centre (IDRC) | Produced fast-growing strains of *O. niloticus* | hatcheries that purchase broodstock from FAC-CLSU | 1993 |
| Genetically Improved Farmed Tilapia (GIFT) | Genetic Improvement of Farmed Tilapia | 1988-1997 | Institute of Aquaculture Research, AKVAFORSK, Norway, FAC-CLSU, ICLARM, BFAR-NFFTC, UPMSI | Asian Development Bank and United Nations Development Programme | Produced fast-growing strains of *O. niloticus* and demonstrated that *O. niloticus* respond positively to selection | GIFT (Genetically Improved Farmed Tilapia) | 1997 |
| GenoMar Supreme Tilapia (GST™) | | 1999-2002 | | GenoMar | Application of DNA genotyping technology, selection differential increased, and total genetic gain on growth rate was 40% higher than the ninth-generation GIFT | GenoMar Philippines, Inc. | 2002 |
| Genetically Male Tilapia also called "YY" (YY male/ GMT) | Genetic Manipulation for the Improvement of Tilapias | 1988-1997 | University of Wales, Swansea, FAC-CLSU, BFAR-National Freshwater Fisheries Technology Center (NFFTC) | Overseas Development Administration (ODA) | Produced genetically male tilapia for grow-out and YY breeders for fingerling production | Produced by Fishgen Ltd. and by Phil-Fishgen and its accredited hatcheries in the Philippines | 1995 |
| Genetically Enhanced Tilapia - Excellent (GET-EXCEL) | | 2002 | BFAR-NFFTC | DA-BAR | Combining strain crosses and adopting within family selection of four different strains of *O. niloticus* | produced by NFFTC and its accredited multipliers | 2000 |
| Brackishwater Enhanced Selected Tilapia (BEST)<br><br>Cold-tolerant tilapia (COLD) | Development of Saline and Cold tolerant Tilapia | 1998-present | FAC-CLSU, BFAR-NFFTC, University of the Philippines-Visayas | DA-BAR | Formed a base population from four different *Oreochromis* species by combining best performing purebreds and crossbreeds after rigid evaluation in different environments | produced by NFFTC and its accredited multipliers | 2003<br><br>2005 |
| Molobicus | Development of Saline Tolerant Tilapia Hybrid (Molobicus Program) | 1998-present | BFAR-National Integrated Fisheries Technology Development Center (BFAR-NIFTDC) | Philippine Council for Aquatic Marine Resources and Development (PCAMRD) and Centre de Cooperation Internationale en Recherche Agronomique pour le Development (CIRAD) | Developed saline tilapia hybrids through hybridization using *O. niloticus* and *O. mossambicus* | produced by NIFTDC and its accredited multipliers | ? |
| (SEAFDEC-Selected Strain (SST) | | 1999-? | Southeast Asian Fisheries Development Center - Aquaculture Department (SEAFDEC/ AQD) | | Produced fast growing strain of *O. niloticus* (Chitralada stock) from modified mass selection technique with collimation technique and developed a small-farm, low-cost selection program | SEAFDEC-AQD | ? |

**Box 1.** Strains generated from the various tilapia breeding programs in the Philippines

**FaST strain**

FAC-CLSU which is responsible for the development of FaST or FAC-Selected Tilapia (or FAC-selected and IDRC) collaborated with two Canadian institutions, the International Development Research Centre (IDRC) and University of Dalhousie to produce a fast-growing tilapia using within family selection, starting with available strains of Nile tilapia (known as "Taiwan", "Singapore", "Thailand", and "Israel" which are generally referred to as "Philippine strain" (Bolivar *et al.*, 1994)). Selection for the nineteen full sib groups was based on body weights at 16 weeks of age, and the heaviest individuals from separate families were mated (1 male: two females). An estimated genetic gain in body weight of 12% per generation was observed after 12 generations of selection. Comparison of the growth rate of FaST and GIFT (Bolivar and Newkirk, 2002; Ridha, 2006) showed no significant difference between both strains, but in terms of survival rate, GIFT was found to have higher (23%) survival (Ridha, 2004). Overall, FaST and GIFT strains had better growth rate, feed conversion ratio and production rates than the non-improved strains (Ridha, 2006). FaST was the first improved tilapia to be commercially disseminated, and was initially distributed in 1993 as the International Development Research Centre (IDRC)-selected tilapia, a reference to the funding agency supporting the research project that resulted in its development (Abella, 2006).

**GIFT strain**

The need to develop low-cost and improved breed of Nile tilapia (*O. niloticus*) in different agro-ecological conditions and farming systems in the Philippines opened the avenue for the collaboration of ICLARM (now WorldFish Center) with other institutions such as the Philippine-based BFAR, CLSU and Marine Science Institute of the University of the Philippines (UP-MSI), and Norwegian Institute of Aquaculture Research (AKVAFORSK) giving rise to the GIFT Project which started in 1988. Launched as a starting point for tropical fish genetic improvement around the world (Gupta and Acosta, 2004), this project was the first to formulate a selective breeding program for *O. niloticus* at the national and international levels (Eknath *et al.*, 1993) for improved breeds of Nile tilapia, and developed the capacity of national institutions in aquaculture genetics research. After the performance assessment of pure bred and crossbred groups among the eight strains (imported wild strains and commercially-farmed strains) from various sources, 25 best-performing groups were selected to construct a synthetic base population, successfully producing a generation that had higher growth and survival performance under on-farm and on-station conditions compared to the local strains farmed in the Philippines. Eknath and Acosta (1998) reported a 12-17% gain over five generations of fish or a 60-85% cumulative increase over the base population. Result of an evaluation of the performance in different agro-ecological countries indicated that the GIFT strain outperformed the non-GIFT strains in terms of growth both in pond and cage culture systems (Dey *et al.*, 2000). The development of GIFT favored an interchange of essential information as well as collaborative research among developing countries across Asia, and among scientific institutes, international organizations, and the private sector (Yosef, 2009). In the Philippines, the development of GIFT led to the creation of other genetically enhanced strains which were referred to as "sons of GIFT" using the GIFT strain as one of the base populations.

**YY-male and GMT**

Simultaneous with the GIFT project was the development of YY-male and GMT producing broodstock under the Genetic Manipulation for the Improvement of Tilapias (GMIT) Program through the collaboration of the University of Wales Swansea (UWS), FAC-CLSU and BFAR-National Freshwater Fisheries Technology Center (BFAR-NFFTC). YY-male technology was conceptualized as a breeding program that generates monosex tilapia (with YY genotypes instead of XY for normal males) providing an alternative to hormonal sex reversal and hybridization. Also known as genetically male tilapia (GMT), the YY-males are called "supermales" with unique capability of siring only genetically male progeny when crossed with normal female with mean progeny sex ratio of 95% male (Mair *et al.*, 1997a). Phil-Fishgen, established at CLSU in 1985, was tasked to disseminate the outputs of the technology (under the registered trade name of GMT licensed by Fishgen Ltd.) and to generate income for the financial sustainability of future FGBP (FishGen Breeding Program) research activities (Tayamen *et al.*, 2006). The YY-male technology provided an effective solution to the problems of early sexual maturation before reaching market size, stunting and overpopulation in tilapia culture systems trough the application of mixed-sex culture system. It also generally solved genetic deterioration in farmed tilapia strains which was then a significant constraint in tilapia production (Mair *et al.*, 1995; Tuan *et al.*, 1998; Abucay *et al.*, 1997). GMT performed much better than the sex-reversed male tilapia in terms of yield, survivability, and food conversion ratios. Moreover, YY/GMT culture is relatively environment-friendly because no hormones are applied while hormone application to broodstock is low (Dunham *et al.*, 2000). Although this technology addressed some of the problems such as early sexual maturation and unwanted reproduction during grow-out that reduces yield, certain issues emerged. Ponzoni *et al.* (2008) pointed out that the hormones used in masculinization pose concerns on food safety since it takes three generations to produce YY-males by the time they are ready for use, the strain could lag behind in terms of genetic gain by 20-45%, and a laboratory with modern facilities to sustain this technology might not be available in many developing countries.

**GET EXCEL**

As envisioned in the Philippine National Tilapia Breeding Program, BFAR-NFFTC continued to develop fast growing GIFT strain, known as Genetically Enhanced Tilapia or GET 2000. BFAR-NFFTC also completed the selection of genetically enhanced base population from the GET 2000 parent line, resulting in the GET 2002 EXCEL. The new strain was a product of a selection program that combined strain crosses and within-family selection with rotational mating using four parent lines: 8$^{th}$ Generation GIFT, 13$^{th}$ Generation FaST, *O. niloticus* Egypt strain, and Kenya strain (Tayamen, 2005). The superior breed of tilapia dubbed as "EXCEL" (short for EXCELlent strain) had comparable advantages over other tilapia strains for entrepreneurial livelihood. Compared to the 8$^{th}$ generation GIFT fish, EXCEL had higher survival, more disease resistant, can withstand temperature fluctuations and enhance growth. To produce additional weight gain of 38 g to every 100 g of the GIFT strain (Ng, 2004), the improved GET EXCEL 2010 was introduced by NFFTC with an estimated 48 g higher growth gain than the origininal GET 2000, that prompted the launching of the "Nationwide Dissemination of GET EXCEL Tilapia" (Tayamen, 2005).

**GST™**

The GST™ strain originated from the "GIFT Super Tilapia" or the fifth generation strain that was developed through the GIFT project. After the project ended in 1999, a nonprofit private foundation known as the GIFT Foundation International (GFI) was established through partnerships with private sector hatcheries in the Philippines (Acosta *et al.*, 2006) to carry out tilapia seed production programs. In order to expand its market GFI contracted GenoMar ASA, a private Norwegian company involved in aquaculture biotechnology, for the development of GIFT Super Tilapia strain (Gjoen, 2001). This commercial alliance enabled GFI to receive an equity position in GenoMar as well as certain rights to produce and distribute improved tilapia strains developed by GenoMar. Since then, GenoMar has conducted selections for three more generations through DNA typing as a replacement to physical tagging (GenoMar, 2008). With this state-of-the art breeding technology, the selection differential has increased very significantly per generation in terms of genetic gain. This improved strain from GenoMar was launched in late 2002 and is believed to have 40% higher genetic gain (in terms of growth) compared to GIFT 9$^{th}$ generation (Gjoen, 2001). In 2003, GenoMar developed the 14$^{th}$ generation of GIFT-derived strains (Yosef, 2009), and continues to produce new generations every nine months with annual genetic gain estimated at more than 15% of the growth (GenoMar, 2008). Experiments have also shown that these improved strains grow faster, more than twice as fast as the local strains (Acosta and Gupta, 2010).

**Box 1.** Strains generated from the various tilapia breeding programs in the Philippines (Cont'd)

**Salt-tolerant strains: Molobicus and BEST**

BFAR-NIFTDC collaborated with PCAMRD and the Centre de Cooperation Internationale en Recherche Agronomique pour le Development (CIRAD), a French scientific organization specializing in development-oriented agricultural research for the tropics and sub-tropics, and launched the Molobicus Program to culture fast-growing tilapia in brackishwater ponds, rivers and estuaries, involving the development of highly saline-tolerant tilapia. Known as Molobicus (combination of *O. mossambicus* and *O. niloticus*), its selection scheme for the first phase involved repeated backcrossing of progenies of *O. niloticus* and the hypersaline *O. mossambicus* to develop hybrids (Rosario *et al.*, 2004), and the next phase comprised selection of fast-growing characteristics from interspecific hybrid population. This rotational crossing scheme was done to preserve genetic variability of the individuals (Camacho *et al.*, 2001; Rosario *et al.*, 2004). Another salt-tolerant hybrid, the Brackishwater Enhanced Selected Tilapia (BEST) was developed by BFAR-NFFTC in collaboration with FAC-CLSU and the University of the Philippines Visayas (UPV) from 1998 to 2005. The BEST strain was developed using three euryhaline tilapia species (*O. mossambicus*, *O. aureus* Steindachner 1864, and *O. spilurus* Günther 1894) and three genetically improved Nile tilapia strains (GIFT, YY/GMT and FAST) as founder stocks. Products of the selection resulted in growth gains of about 86% compared to $F_1$ pure cross of *O. mossambicus* and 24% compared to $F_1$ of *O. mossambicus* x *O. niloticus* Egypt strain. Survival also increased by 24% compared to pure *O. mossambicus* cross and 35% compared to the cross of *O. mossambicus* x *O. niloticus* Egypt strain (Tayamen *et al.*, 2002). The latest stock produced by NFFTC was named "BEST 2010".

Selective breeding of salinity-tolerant strain of Nile tilapia hybrid was also implemented by SEAFDEC/AQD involving hybridization of *O. niloticus* with *O. mossambicus* followed by repeated backcrossing of the hybrid with *O. niloticus* (Basiao, 2001). On the other hand, BEST and *Molobicus* strains were evaluated (Danting pers. comm., 2012) to assess the advantages of these strains. One of the possible advantages is the suitability of the strains to brackishwater environments which could serve as an alternate culture species for shrimps and milkfish when seedstocks of the latter commodities are not available or could be grown in polyculture with other farmed brackishwater species. Another interesting development is on the use of saline-tolerant tilapia for the "greenwater technology" to control Vibriosis disease in shrimp (*Penaeus monodon* Fabricius 1798) farming in brackishwater ponds. The use of saline tilapia was considered bioremediation factor since the greenwater produced by tilapia prevents the occurence of diseases in shrimp farms and helps in controling unwanted weeds.

**Cold-tolerant tilapia**

The inability of tilapia to tolerate low temperatures is a serious concern for commercial aquaculture in colder regions of the Philippines. The optimal temperature for tilapia growth is between 25° and 28°C (Charo-Karisa *et al*, 2005), while numerous adverse effects could include high mortality due to low temperature at 10-12°C, cessation of feeding activity below 16-17°C, and reproductive inhibition below 20°C (Yadav, 2006). Thus, the project on "Development of Cold Tolerant Tilapia" was initiated by BFAR-NFFTC to develop a breed of tilapia which could withstand cold temperatures in northern Philippines like in the Cordillera Autonomous Region (CAR), and in other areas with relatively cooler temperatures (ranging from 10° to 22°C) during the country's cold season. The project envisions to maximize these areas in order to produce additional supply of marketable size tilapia. The base population of the COLD Tilapia as it is now called, is composed of *Oreochromis* species, namely: *O. aureus*, *O. spilurus* and the two improved breeds of Nile tilapia, namely: the 8th Generation GIFT and FaST. The project was implemented in five consecutive years following rigorous evaluation in ponds, tanks and cages under different environments following the communal stocking scheme.

**SST**

The Aquaculture Department of the Southeast Asian Fisheries Development Center (SEAFDEC/AQD) based in the Philippines developed its own growth-enhanced strain starting in 1999, through a simple farm-based size-specific mass selection on previously size graded stock. This was aimed at developing tilapia broodstock improvement program that is low-cost, small-scale, and could be applied under very practical conditions (Lutz, 2004). The SEAFDEC-selected strain or SST was produced from 100 pairs of domesticated Thai Nile tilapia (NIFI) stock, known as Chitralada. SST was developed through a simple mass selection to improve the growth of cage-reared Nile tilapia. Response to selection after one generation of size-specific mass selection was noted at 3%, while the realized heretability was estimated at 16%, a projected improvement of 34% over a 5-year period (Basiao and Doyle, 1999). However, this strain has not been extensively distributed as the other more popular strains such as GET-EXCEL, GST™, GMT and FaST.

## Impacts of Improved Tilapia Strains in the Aquaculture Production of the Philippines

Tilapia has been widely adopted as a substitute for all kinds of wild-caught fishes pushing the global demand for tilapia to yearly increases despite world-wide recessions (Fitzsimmons *et al*., 2011). In the Philippines, the continuous effort of enhancing the overall quality of tilapias by fish breeding institutions has contributed to increased demand for tilapia products in the market (Toledo *et al*., 2009). As a result, farmed tilapia costs much cheaper than chicken, becoming an important fish and protein source in the diet of poor Filipinos who had been consuming less milkfish, roundscad (*Decapterus* spp.) and other native freshwater fishes (Edwards, 2006; ADB, 2005). Moreover, the affordability and stable market price of tilapia coupled with income elasticity of demand among poorer populations in the Philippines make it a significant food fish to financially-challenged Filipinos (Yosef, 2009). As a matter of fact, after the introduction of enhanced tilapia strains that led to increased production, the average per capita consumption of tilapia in the Philippines had risen by 474% from 0.66 kg (before the introduction) to 3.13 kg per year in 2010 (Yosef, 2009; BAS, 2012). Figures have shown that in the past decade from 2002 to 2012, tilapia production achieved a remarkable 50% growth with maximum production of 303,169 metric tons (MT) in 2012, accounting for about 6% of the country's total fisheries production in the same year (BAS, 2012). This phenomenon could be attributed to fish farmers' access to wide range of tilapia strains, and increased resources and labor force since tilapia farming operations became widespread. Since 68% of the total tilapia seeds produced in the country in 2003 comprised GIFT and GIFT-derived tilapia strains (ADB, 2005), this validates the significant contribution of this genetic improvement to the growth of the country's tilapia production that was recorded at 145,869 MT in 2004, making the Philippines third among the top tilapia producers of the world.

In 2011 however, other countries especially Indonesia and Thailand have remarkably increased their tilapia production pushing the Philippines behind at the top five. In this connection, the Philippines developed its Master Plan for the Tilapia Industry that included a target to increase tilapia production from 122,000 MT in 2002 to 250,000 MT in 2010 (DA, 2002), and in 2008, the expected volume had been exceeded. Nonetheless, increases in Philippine tilapia production had not been as pronounced as in other Asian countries due to various management obstacles encountered (Yosef, 2009). Although many Filipinos have benefited from improved tilapia strains, gains could not be measured in terms of the number of consumers only but also on the number of Filipinos who have benefited from the tilapia industry (CGIAR, 2006).

## Other Applications of Tilapia Genetic R&D

In genetic research of tilapia, most studies used technologies such as DNA markers for genetic characterization, gene mapping, and functional genomics, while molecular-based knowledge in tilapia genetics and stock management have been confined to some developed and developing countries in Asia, including the Philippines (Galman-Omitogun, 2005). Despite being recognized as one of the most successful countries to apply traditional genetic R&D in its breeding programs, the Philippines has yet to boost its effort in the area of genetic applications in aquaculture. Until now, the country still lacks the capacity to utilize advanced genetic technologies as tools for management and monitoring, and for exploring the potentials of tilapia genetic resources for production enhancements. Development of novel strains and improvement of stocks through genetics and biotechnology is a vital aspect in tilapia aquaculture that should be addressed to secure its sustainability and profitability. Under the National Integrated Research Development and Extension Program (Aquaculture) of the Philippines and in the formulation of the Aquaculture Research Development and Extension Agenda of DA-BAR and PCAARRD (DA-BAR, 2001), earlier genetic works were centralized in creating improved tilapia strains through genetic improvement from simple species-crossing to organized selection programs, to enhance their viability, reproductive fitness, and adaptability to environmental changes and stress (Kuo and Abella, 1982). While improved tilapia strains have been produced through traditional selective breeding, hybridization, cross-breeding, sex reversal or combination of these techniques, most of these programs, *i.e.* selective breeding, have been conducted typically in favorable environments where growth is expected to be high and results that bring forth additive genetic variables exploited from such programs (Tran *et al.*, 2011).

From the previous experimental breeding programs conducted in the Philippines, tilapia research during the past three decades were mostly based on the growth performance of tilapia in different farm environments (Galman *et al.*, 1988; Basiao *et al.*, 1996; Mair *et al.*, 1997b; Romana-Eguia and Eguia, 1999; Basiao *et al.*, 2005; Romana-Eguia *et al.*, 2010), and on the development and determination of strains suitable for saline waters (Villegas, 1990; Romana-Eguia and Eguia, 1999; Rosario *et al.*, 2004; Tayamen *et al.*, 2002). In addition, the use of more powerful molecular techniques was also recently started although other protein markers were already used in few studies in the previous years. Some of the genetic researches on tilapia in the Philippines are shown in **Table 3** which includes only the studies conducted by or in collaboration with, government or national institutions, and those studies which used different strains in the methodologies, specifically the strains developed in the Philippines. While the table summarizes the available information, all experiments on genetic technologies in tilapia aquaculture R&D might not have been necessarily enumerated. Nonetheless, **Table 3** would provide valuable information for various aspects of aquaculture practices with special highlight in selective breeding programs and genetic improvements of aquaculture stocks.

It should be recalled that in the beginning, efforts of the Philippines in analyzing the genetic aspects of tilapia focused on two areas, *i.e.* genetic differentiation of cultured tilapia stocks using morphometric and meristic characters (Pante *et al.*, 1988) as well as biochemical or protein markers for allozyme analysis (Pante and Macaranas, 1989; Macaranas *et al.*, 1993, 1995), and genetic characterization of stocks to basically address the problems of deteriorating quality of tilapia fingerlings and reduced performance of farmed tilapias in 1980s (Taniguchi *et al.*, 1985; Macaranas *et al.*, 1986) using allozyme electrophoresis which was widely used for genetic characterization during that period. The results revealed the founder and bottleneck effects in cultured tilapia stocks as well as widespread introgression of genes from the less desirable species *O. mossambicus* to the commercial Nile tilapia. This finding actually signaled

**Table 3.** Genetic researches on tilapia in the Philippines in the past 20 years

| Research areas/titles | Technology | References |
|---|---|---|
| Genetic enhancement of tilapia thru breeding program | Selective breeding techniques, hybridization, crossbreeding | Eknath *et al.* (1993) |
| Genetic characteristics of food fishes | | |
| Introgressive hybridization in cultured tilapia stocks in the Philippines | Allozyme genotyping | Taniguchi *et al.* (1985) |
| Electrophoretic evidence for extensive hybridization gene introgression into commercial *O. niloticus* stocks in the Philippines | Allozyme genotyping | Macaranas *et al.* (1986) |
| A preliminary study on the use of canonical discriminant analysis of morphometric and meristic characters to identify cultured tilapias | Morphometric and meristic analysis | Pante *et al.* (1988) |
| Documentation and genetic characterization of different tilapia strains | Allozyme genotyping | Macaranas *et al.* (1993); Pante and Macaranas (1989) |
| Genetic improvement of farmed tilapias: biochemical characterization of strain differences in Nile tilapia | Allozyme genotyping | Macaranas *et al.* (1995) |
| YY male technology | Sex manipulation | Abucay *et al.* (1997); Mair *et al.* (1997a, 1997b) |
| Multilocus DNA fingerprinting and RAPD reveal similar genetic relationships between strains of *Oreochromis niloticus* (Pisces: Cichlidae) | DNA markers (minisatellites, RAPD) | Naish *et al.* (1995) |
| Genetic Diversity in farmed Asian Nile and Red Hybrid Tilapia stocks evaluated from microsatellite and mitochondrial DNA analysis | DNA markers (microsatellites, RFLP) | Romana-Eguia *et al.* (2004) |
| Genetic changes during mass selection for growth in Nile tilapia, *Oreochromis niloticus* (L.), assessed by microsatellites | DNA markers (microsatellites) | Romana-Eguia *et al.* (2004) |
| DNA barcoding of different tilapia strains in the Philippines* | DNA barcoding (mitochondrial DNA, nuclear DNA) | |
| Mining molecular markers in the gene of cultured Nile tilapia associated with disease resistance** | DNA markers | |

* On-going project of the National Fisheries Research and Development Institute, Philippine Bureau of Fisheries and Aquatic Resources
** On-going project of Central Luzon State University, Nueva Ecija, Philippines

the start of research on the genetic improvement of tilapia in the Philippines.

Nevertheless, very few research studies employed the polymerase chain reaction (PCR)-based methods, where the earliest record used multilocus DNA fingerprinting (mini-satellite markers) and random amplified polymorphic DNA (RAPD) analysis to detect the genetic relationship of cultured strains of *O. niloticus* found in the Philippines (Naish *et al*., 1995). A subsequent PCR-based study was performed a decade after by Romana-Eguia *et al.* (2004) using more powerful DNA markers such as mitochondrial-restriction fragment length polymorphism (mitochondrial-RFLP) and microsatellites to estimate the probable genetic variability and possible erosion of the gene pool of different tilapia stocks found in the Philippines. The results revealed that Nile tilapia stocks were slightly divergent from red tilapia stocks with improved Nile tilapia stocks being more diverse compared to strains not subjected to any breeding program.

Although not strictly a genetic technology, gamete cryopreservation has a potential role in genetic conservation of wild, endangered wild or cultured stocks (Hulata, 2001). Cryopreservation and the establishment of 'Tilapia Sperm Bank' were started by BFAR-NFFTC in 2003 with technical assistance from the Institute of Aquaculture, University of Stirling, UK. Now, the gene bank has a collection of different strains of tilapia founder stocks from different countries, 281 straws from the founder stocks, and 480 straws of fish samples from selective breeding programs (De la Rosa, 2003; ADB, 2005). Breeding trials conducted by the WorldFish Center to determine the precise magnitude of genetic gains achieved during the development of GIFT made use of the semen from GIFT founder stocks that were deposited in the Sperm Bank (ADB, 2005). Results of experiments that utilized cryopreserved tilapia spermatozoa showed that accumulative genetic gain in growth rate of GIFT strain is still high (at least 64%) in the progeny produced from spermatozoa of the ninth generation (produced in Malaysia) compared to the progeny produced from cryopreserved spermatozoa of the base population (generation zero produced in the Philippines), confirming that GIFT is a superior Nile tilapia strain (Khaw *et al*., 2008). Despite the abundant collection of tilapia sperm at BFAR-NFFTC Tilapia Sperm Bank, this resource has not yet been adequately used or tested under local initiatives.

## Advocators of Philippine Tilapia Genetic Research

Molecular-based genetic approaches in Philippine tilapia aquaculture are still in its infancy due to insufficient financial resources and/or limited human resources with capacity or expertise impeding further development of the country's tilapia genetic R&D. Over the past decades, various institutions from the government and private sector have been active in conducting fisheries and aquaculture research, specifically spearheading aquaculture genetic studies, *e.g.* BFAR-NFFTC, CLSU, UPV in Iloilo, and SEAFDEC/AQD. At present, tilapia breeding and genetic improvement are performed only by agencies with the human resource, expertise and facilities required, and mandates to develop and distribute improved tilapia strains to farmers (Tayamen *et al*., 2006). The main government institutions such as BFAR-NFFTC and FAC-CLSU are responsible not only in the production and dissemination but also in the depository (*i.e.* Tilapia Sperm Bank) and genetic management of tilapia species and strains for genetic diversity maintenance. While FAC-CLSU is mandated to do R&D works on tilapia genetics, NFRDI has the mandate of ensuring the welfare of the fisheries sector through fisheries R&D, and in management, conservation, and protection of the country's aquatic resources. Nevertheless, continuous improvement of tilapia strains is still conducted by FAC-CLSU, BFAR-NFFTC, and SEAFDEC/AQD with performance evaluation still the most prevalent activity in tilapia aquaculture. At SEAFDEC/AQD, different tilapia strains are used to determine the most suitable for brackishwater environments, while on-farm performance comparisons are being carried out by BFAR-NFFTC. The tilapia road map charted by NFRDI includes the conduct of genetic-related studies that would expedite the growth of tilapia production and aid in developing more efficient management and monitoring practices and strategies that subsequently contribute to achieving the industry's goal of sustainability. At present, NFRDI is working on DNA markers for farmed tilapias and suitable genetic markers to differentiate the commercially-used strains for genetic protection and conservation purposes. FAC-CLSU also focuses on genetic studies to determine the molecular markers associated with disease resistance in farmed tilapia.

## Challenges and Future Prospects

The recent decade marks the period where increasing numbers of projects explore the applications of molecular approaches in economically-important aquaculture species, which could be greatly attributed to the increasing number of scientists with expertise in fish genetics. Thus, with increasing human resources, genetic research in farmed tilapia could expand and progress well. Simultaneous with the selection programs is the utilization of molecular genetics techniques, such as molecular markers for science-based stock monitoring, assessment and management in tilapia aquaculture, and DNA marker-assisted selection. Nonetheless, success of future aquaculture breeding programs would mainly come from the pool genetic information compiled to be integrated into specific programs. One of the current trends in aquaculture genetic research is the discovery and mapping of quantitative trait loci (QTLs) or genes coding for characters with important productive value that could be subsequently used to speed up genetic gain of a target species through MAS breeding programs. Preliminary works on the development of new tilapia strains based on mapping QTLs using molecular markers such as microsatellites and anonymous fragment length polymorphism (AFLP) had been initiated as early as 1995. Based on the current capability level of the Philippines in terms of aquaculture research, performing high-level and more expensive technologies such as QTL identification would be very challenging. In tilapia genetic research at present, venturing into this technology might not be practical but will certainly be needed in the future. Thus, future molecular-based researches should focus on more tangible objectives that are urgent and equally important (Acosta *et al*., 2006; Toledo *et al*., 2009) although some insights were inferred from the present program framework implemented in two main breeding nuclei in the country (*i.e.* BFAR-NFFTC and FAC-CLSU).

Therefore programs that aim to ensure the maintenance of genetic integrity of improved tilapia stocks should be developed, and a prerequisite of establishing good culture program is having stocks with relatively high genetic variation. Assessing the diversity of existing tilapia genetic resources is essential not only in the development of effective management schemes but also in protecting and conserving the economic traits (*e.g.* growth rate, survival, and disease and temperature resistance) of improved stocks. Genetic gains established during the breeding programs can be negatively impacted when genetic variability reduction occurs. Determining the genetic variation in cultured stocks is also important in preventing the release of mixed hatchery-produced seeds which could not be detected by the appearance of the fish (An *et al*., 2011). Application of molecular markers, especially microsatellite DNA, is useful in addressing numerous aquaculture problems such as discrimination of wild and hatchery stocks (Ha *et al*., 2009), detection of inbreeding or genetic introgression in cultured stocks (Sukmanomon *et al*., 2012), strain evaluation for broodstock selection (Brown *et al*., 2007), and determination of genetic status and loss of genetic diversity of cultured stocks (Wang *et al*., 2012). The only detailed information available on genetic diversity of Philippine tilapia stocks was from Romana-Eguia *et al*. (2004), which indicated that Nile tilapia stocks such as GIFT, GMT, and FaST strains have high genetic diversity. However, this information was released almost a decade ago and no subsequent reports ensued while genetic monitoring of tilapia seeds and broodstocks in the country's breeding nuclei (*i.e.* BFAR-NFFTC and FAC-CLSU) are currently not performed. Therefore, a program that promotes the conduct of continuous follow-ups and routine monitoring (*e.g.* checking of selection response, detecting signs of inbreeding depression, assessing stocks with valuable source of genes for future mitigation of genetic erosion) by national institutions, especially the country's tilapia breeding nuclei, would greatly help in maintaining tilapia genetic resources. Moreover, the efficiency of breeding programs in implementing quality checking schemes, an important issue that needs to be frequently addressed, could also be assessed. Genetic diversity monitoring should be a top priority and integrated in present monitoring programs as this would contribute to the baseline for science-based plans and actions such as preventing possible reductions in genetic variation of present healthy stocks and developing measures to counter possible consequences elicited by genetic deterioration.

The introduced and invasive blackchin tilapia (*Sarotherodon melanotheron*), locally known as "tilapiang Gloria", had been infesting fishponds and other water tributaries in Bulacan and Bataan Provinces of the Philippines (Ordoñez *et al*., 2014) and regarded as pests in these provinces. Invasion of blackchin tilapia or any other invasive species in different water systems would not only pose serious threats to fisherfolk's livelihoods and the aquatic ecosystem but could also bring about possible undesirable effects on the genetic makeup of natural tilapia populations. Interspecific hybridization resulting to genetic introgression could lead to genetic degradation and poor quality of tilapia stocks, which already happened in the 1980s (Taniguchi *et al*., 1985; Macaranas *et al*., 1986). Therefore, the application of genetic analysis using DNA markers (*e.g.* microsatellites) would address such concerns, especially in detecting the presence of hybrids of *S. melanotheron* and *Oreochromis* spp. and the extent of introgression between such species in a certain population. Assessing the ecological impacts of new strains after escaping to the wild should also be part of monitoring programs. Ecological risks in tidal ponds, open water cages and offshore ocean culture systems are relatively high because of the direct contact between the farm and natural waters (Leung and Dudgeon, 2008). Mitigating risks is important considering that vast brackishwater areas are now being targeted for the expansion of tilapia farming and the introduced species could become invaders of food and space, transmit diseases and cause inbreeding with wild species.

In Lake Buhi of the Philippines, the introduction of tilapia in freshwater aquaculture systems was reported to have caused the near extinction of the indigenous sinarapan (*Mistichthys luzonensis* Smith 1902) populations (Yap *et al*., 1983) and also resulted in significant ecological and economic impacts in the tropics and subtropics (Canonico *et al*., 2005). Efficient tools for tracing the stocks from the origins of escaped individuals could include the application of genetic techniques such as genetic analysis using microsatellite markers or SNPs. Once the source of escapees has been pinpointed, actions to prevent further introduction of farmed fish stocks to natural habitats could be taken. This investigative strategy makes it possible to come up with better risk assessment and management schemes. However, the release of non-native tilapia and carp species in Southeast Asian freshwater systems had substantially added to total fish community biomass with at best, mild impacts on native fish communities as reported by Arthur *et al*. (2010). Another practical and immediate application of genetic markers is parentage assignment (Norris *et al*., 2000) since determining the stock parentage by pedigree tracking is critical to avoid the offspring of few individuals from dominating the replacement broodstocks (McAndrew and Napier, 2011). In BFAR-NFFTC, the tedious work of physical tagging is still done which could be very difficult when tagging individuals at their early stages (Subasinghe *et al*., 2003). Using DNA microsatellite markers to serve as "genetic tags" could assist and facilitate tracking and identifying pedigrees in breeding programs thus, avoiding the risk incorporating physical tags in the human food chain (McAndrew and Napier, 2011).

Therefore, the development of "genetic tags" or "barcodes" would be useful in protecting the intellectual property rights (IPR) of the breeders' products. To date, only trademarks are effectively protectable (as in GST™ and GMT) and there is no policy that restricts breeders' products from being utilized in other research works (Acosta *et al*., 2006). In the advent of whole-genome sequencing technologies, identifying strain-specific markers (*e.g.* SNPs) has become more efficient, cheaper, and relatively easier to undertake. Identification of genetic tags could serve as scientific basis for IPR policies and help prevent intellectual property theft. In the Philippines, tilapia is still not included or covered by existing Philippine laws on fish export/import and regulations that concern protection of aquatic biodiversity. Given the wide research areas, investments to support such efforts should be intensified to ensure that the gains which have been achieved are sustained (Sevilleja, 2006). Income generating projects of public sector might not suffice the activities' heavy demands so that support should also be sought from the private sector. Thus, private-public partnership can play a vital role in keeping these R&D activities running through collaborative arrangements to ensure sustainable financial resources for genetics research (Acosta *et al*., 2006). With the creation of the DA-Biotech Program, a government program that aims to modernize Philippine agriculture through biotechnology, projects exploring genetics and genomics in aquaculture species are expected to increase in the coming years. Again, these activities are only possible if there is sufficient manpower with the needed technical skills. Once proven to be successful, these researches could lead to successful tilapia aquaculture management, ensuring that production of high-quality tilapia could be sustained for food security of the country.

## Conclusion and Way Forward

Genetic and genomic techniques have benefited tilapia aquaculture in many ways. Most of the applications involve the use of DNA markers for monitoring and management but a considerable portion of these researches paid attention to genome mapping. With the generation of genome-scale data becoming easier and more efficient, genomic and transcriptomic data of tilapia has been rapidly emerging. The tremendous amount of data compiled through the use of next generation technologies would provide invaluable information for future marker-assisted breeding and transgenesis of tilapia. There is no doubt that success of the tilapia industry in the Philippines has been largely attributed to the development of genetics-based applications. Utilizing genetic principles and tools in various breeding programs enabled the improvement of stock quality and performance, contributing to the steady increase of the country's tilapia production.

However, despite successes in producing novel strains with improved qualities, the country's tilapia aquaculture sector continues to face challenges particularly in the area of genetic research that could contribute to the sustainability and advancement of the whole industry. The bottlenecks include inadequate monitoring of the genetic status of present farmed stocks and limited technical persons with genetic research background and skills. Although genetic studies in tilapia aquaculture has already started in the Philippines, but this is still far from marking their significant impacts on the sector's performance. Furthermore, advanced DNA-based studies like MAS breeding for Philippine tilapia research would strongly rely on scientific information that can only be produced using DNA fingerprinting technologies. Once such efforts become successful, knowledge could be transferred to other breeding programs, which in turn would contribute to ensuring the prosperity and stability of the country's entire aquaculture sector.

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## About the Authors

**Mr. June Feliciano F. Ordoñez** and **Dr. Mudjekeewis D. Santos** are Researcher and Scientist I, respectively of the National Fisheries Research and Development Institute (NFRDI) of the Philippine Bureau of Fisheries and Aquatic Resources, Department of Agriculture, 101 Mother Ignacia St., Quezon City, Philippines.

**Mr. Melchor M. Tayamen** is the Director of the National Fisheries Research and Development Institute (NFRDI) of the Philippine Bureau of Fisheries and Aquatic Resources, Department of Agriculture, 01 Mother Ignacia St., Quezon City, Philippines.

# CALENDAR OF EVENTS

| Date | Venue | Title | Organizer(s) |
|---|---|---|---|
| | | 2014 | |
| 11-15 August | Binangonan, Philippines | Training Course on Tilapia Hatchery and Grow-out Operations | SEAFDEC/AQD |
| 13-14 August | Pattaya, Thailand | 1st Meeting of a Public-Private Working Group on Aquatic Animal Health and ASEAN Workshop on Minimizing Risks Associated with Transboundary Aquatic Animal Disease | MARKET |
| 13-15 August | Da Nang, Vietnam | Training of Trainer on Facilitating Fisheries Information Gathering Through Introduction of Community-based Fisheries Management | SEAFDEC/TD |
| 18-22 August | Binangonan, Philippines | Training Course on Catfish Culture | SEAFDEC/AQD |
| 19-21 August | Tawau, Malaysia | Sub-regional Technical Meeting for Finalizing Work Plan of Activities of SEAFDEC Joint Program for Tuna Research in Sulu and Sulawesi Seas | SEAFDEC/TD |
| 20-21 August | Pattaya, Thailand | Regional Workshop on Regional Fishing Vessels Record (RFVR) Database Development and Management | SEAFDEC/TD |
| 26-28 August | Kuala Lumpur, Malaysia | Core Experts Meeting on Purse Seine Fishery in the Southeast Asian Region | SEAFDEC/MFRDMD |
| 31 Aug-1 Sep | Palembang, Indonesia | 2nd Regional Consultation on Sustainable Management of Eel Fisheries Resources and Aquaculture Production in the Region | SEAFDEC Secretariat |
| 1-9 September | Tigbauan, Philippines | Training Course on Detection of Viral Diseases in Marine Fish & Crustaceans | SEAFDEC/AQD |
| 1-12 September | Igang, Philippines | Training Course on Seaweed Farming | SEAFDEC/AQD |
| 2-4 September | Palembang, Indonesia | International Conference on Inland Capture Fisheries | Indonesia |
| 4-5 September | General-Santos, Philippines | 16th National Tuna Congress & Trade Exhibition | Philippines |
| 8-12 September | Binangonan, Philippines | Training Course on Freshwater Prawn Hatchery and Grow-out Operations | SEAFDEC/AQD |
| 8 Sep-22 Feb 15 | Internet | Distance Learning Course: Basic Principles of Health Management in Aquaculture | SEAFDEC/AQD |
| 15-29 September | Samut Prakan, Thailand | Regional Training Course on Essential EAFM and Extension Methodologies | SEAFDEC/TD |
| 21-25 September | Merida, Mexico | 2nd World Small-Scale Fisheries Congress (2WSFC) | TBTI |
| 23-25 September | Kota Kinabalu, Malaysia | Regional Technical Consultation on Guidelines on Preventing the IUU Fish and Fishery Products to Supply Chain | SEAFDEC/MFRDMD & Secretariat |
| 13-17 October | Binangonan, Philippines | Training Course on Catfish Hatchery and Grow-out Operations | SEAFDEC/AQD |
| 14-16 October | Malaysia | Expert Group Meeting on Drafting of Regional Catch Documentation System | SEAFDEC/MFRDMD & Secretariat |
| 14 Oct-5 Nov | Tigbauan, Philippines | Training Couse on Mud Crab Hatchery, Nursery & Grow-out Operations | SEAFDEC/AQD |
| 4-6 November | Cairns, Australia | 7th RPOA Coordination Committee Meeting | RPOA/IUU |
| 25 Nov-4 Dec | Philippines | Training Course on Community-based Freshwater Aquaculture for Remote Rural Areas of Southeast Asia | SEAFDEC/AQD |
| 1-3 December | Ubon Ratchathani, Thailand | 37th Meeting of SEAFDEC Program Committee | SEAFDEC |
| 4-5 December | Ubon Ratchathani, Thailand | 17th Meeting of the Fisheries Consultative Group of the ASEAN-SEAFDEC Strategic Partnership (FCG-ASSP) | ASEAN & SEAFDEC |
| 16-18 December | Malaysia | 1st Regional Technical Consultation on Regional Catch Documentation System | SEAFDEC/MFRDMD & Secretariat |
| 9-11 December | Nay Pyi Taw, Myanmar | Regional Technical Consultation on Development and Use of Alternative Dietary Ingredients in Aquaculture Feed Formulations | SEAFDEC/AQD |
| | | 2015 | |
| 20-22 January | HCM City, Vietnam | 3rd OIE Global Conference on Aquatic Animal Health: "Riding the wave to the future" | OIE |
| 26-30 January | FAO HQ, Italy | Global Inland Fisheries Conference | FAO |

## Southeast Asian Fisheries Development Center (SEAFDEC)

### What is SEAFDEC?

SEAFDEC is an autonomous intergovernmental body established as a regional treaty organization in 1967 to promote sustainable fisheries development in Southeast Asia.

### Mandate

To develop and manage the fisheries potential of the region by rational utilization of the resources for providing food security and safety to the people and alleviating poverty through transfer of new technologies, research and information dissemination activities

### Objectives

- To promote rational and sustainable use of fisheries resources in the region
- To enhance the capability of fisheries sector to address emerging international issues and for greater access to international trade
- To alleviate poverty among the fisheries communities in Southeast Asia
- To enhance the contribution of fisheries to food security and livelihood in the region

### SEAFDEC Program Thrusts

- Developing and promoting responsible fisheries for poverty alleviation
- Enhancing capacity and competitiveness to facilitate international and intra-regional trade
- Improving management concepts and approaches for sustainable fisheries
- Providing policy and advisory services for planning and executing management of fisheries
- Addressing international fisheries related issues from a regional perspective


TD


MFRD


Secretariat


AQD


MFRDMD


## SEAFDEC Addresses

### Secretariat

P.O. Box 1046
Kasetsart Post Office
Bangkok 10903
Thailand
Tel: (66-2)940-6326
Fax: (66-2)940-6336
E-mail: *secretariat@seafdec.org*
*http://www.seafdec.org*

### Training Department (TD)

P.O. Box 97
Phrasamutchedi
Samut Prakan 10290
Thailand
Tel: (66-2)425-6100
Fax: (66-2)425-6110 to 11
E-mail: *td@seafdec.org*
*http://www.seafdec.or.th*

### Marine Fisheries Research Department (MFRD)

2 Perahu Road
off Lim Chu Kang Road
Singapore 718915
Tel: (65)6790-7973
Fax: (65)6861-3196
E-mail: *ava_mfrd@ava.gov.sg*
*http://www.seafdec.org*

### Aquaculture Department (AQD)

**Main Office:** Tigbauan,
5021 Iloilo, Philippines
Tel: +63 33 511 9171
Fax: +63 33 511 8709, 511 9170
**Manila Office:** Rm 102 G/F
Philippine Social Science Center (PSSC)
Commonwealth Avenue, Diliman
Quezon City 1101 Philippines
Tel & Fax: (63-2) 927-7825
E-mail: *aqdchief@seafdec.org.ph*
*http://www.seafdec.org.ph*

### Marine Fishery Resources Development and Management Department (MFRDMD)

Taman Perikanan Chendering,
21080 Kuala Terengganu, Malaysia
Tel: (609) 616-3150
Fax: (609) 617-5136
E-mail: *mfrdmd@seafdec.org.my*
*http://www.seafdec.org.my*

**The first prize drawing winner for Primary 1-2, *Simone Ngiam Zhengxuan*, from the national drawing contest in Singapore**

*National Drawing Contests were organized in all ASEAN-SEAFDEC Member Countries as part of the preparatory process for the ASEAN-SEAFDEC Conferene on Sustainable Fisheries for Food Security Towards 2020 "Fish for the People 2020: Adaptation to a Changing Environment" held by ASEAN and SEAFDEC in June 2011 in Bangkok, Thailand, in order to create awareness on the importance of fisheries for food security and well-being of people in the region.*