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

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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.

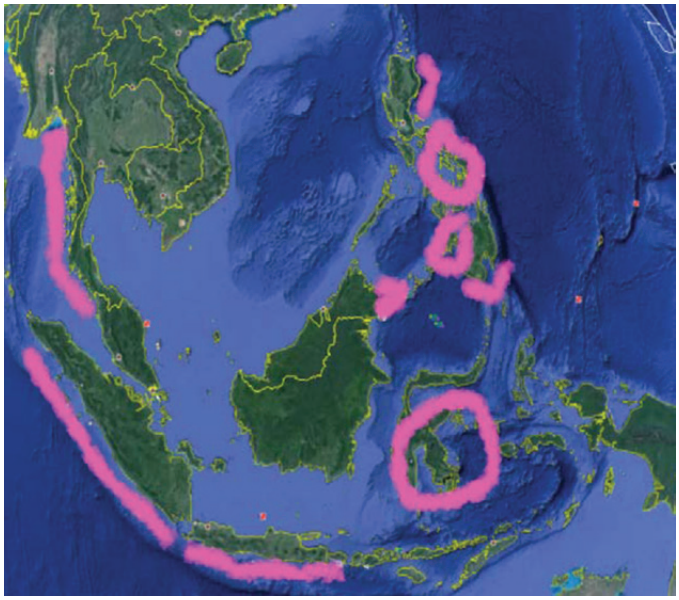


Fig. 1. Distribution of *Anguilla* spp. in Southeast Asia

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 *A. interioris* *A. nebulosa nebulosa* *A. marmorata* *A. borneoensis* *A. bicolor bicolor* *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) Dedy Duryadi Solihin Kadarwan Soewardi Laurent Pouyaud Zhaojun Shao Patrick Berrebi	Malaysia
A. marmorata *A. bicolor pacifica*	Ecology (migration and habitat use) Life stage Yellow stage (immature) 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. *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) Naoko Chino Dung Quang Le	Vietnam
A. luzonensis	Ecology (spawning area and early life history) 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) Michael Miller Jun Aoyama Shun Watanabe Tatsuki Yoshinaga Katsumi Tsukamoto	Philippines
A. bicolor bicolor	Ecology (species distribution)	*A. bicolor bicolor* has an extended species distribution range into Peninsular Malaysia.	T. Arai (2012) N. Chino S.Z. Zulkifli 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) Xin Qi Shaowu Yin	Philippines

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

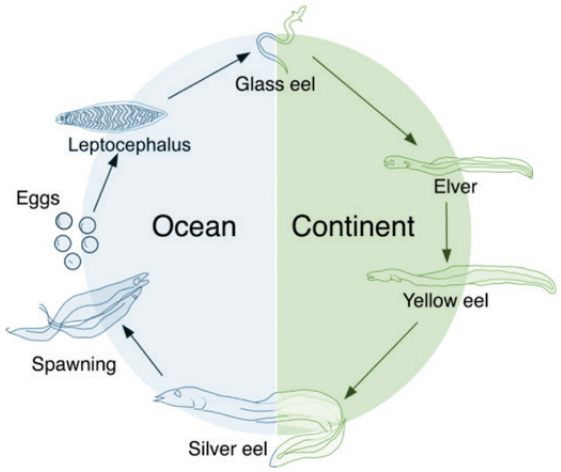
Eel Species	Topic of investigation	Major findings	Author(s)	SEA Country
A. bicolor	Nutrition (effects of attractant on protein, fat and energy retention on eel juvenile Life stage (elver)	Treatment without attractants added in paste feed showed best results in protein and energy retention while pasta feed with squid oil gave the best retention of fats in the muscle of *A. bicolor*.	S. Yudiarto (2012) M. Arief Agustono	Indonesia
A. marmorata *A. bicolor pacifica*	Toxicology (organotin accumulation in fish migrating between sea and freshwater) 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) N. Chino D.Q. Le H. Harino	Vietnam
A. bicolor bicolor *A. celebesensis* *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) T. Arai	Indonesia
A. marmorata	Toxicology (trace metal and methylmercury contamination in soft tissues of eel) 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) Duc Cu Nguyen Hiroya Harino Naoya Kakutani Naoko Chino Takaomi Arai	Vietnam
A. marmorata	Toxicology (heavy metals contamination in muscle tissue of eel) 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) Kotaro Shirai Duc Cu Nguyen Nobuyuki Miyazaki Takaomi Arai	Vietnam
A. marmorata *A. bicolor pacifica* *A. bicolor bicolor*	Ecology (migration and habitat preferences of eels in Cagayan and Kalinga Province, Philippines) 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) Apolinario V. Yambot Jen-Chieh Shiao Yoshiyuki Iizuka Wann-Nian Tzeng	Philippines
A. bicolor bicolor	Ecology (early life history and location of spawning ground) 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) 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) H. Taraschewski M. Thairungroj Anantaphruti W. Maipanich 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 *A. bicolor pacifica* *A. celebesensis* *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) Jun Aoyama Michael J. Miller Sam Wouthuyzen Takaomi Arai Katsumi Tsukamoto	Indonesia
A. marmorata	Ecology (inshore migration) 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) 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) Michael J. Miller Katsuni Tsukamoto	Philippines
A. celebesensis *A. marmorata* *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) Michael J. Miller 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) 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) M. Marui M.J. Miller K. Tsukamoto	Indonesia
A. marmorata	Ecology (period of deposition of growth increments in the otolith of tropical eel) 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) T. Arai M.J. Miller D. Limbong 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 *A. marmorata* *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) J. Aoyama S. Ishikawa M.J. Miller T. Otake I. Inagaki T. Tsukamoto	Indonesia
A. celebesensis *A. marmorata* *A. bicolor pacifica*	Ecology (species composition, early-life history species migration) 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) T. Arai M.J. Miller D. Limbong K. Tsukamaoto	Indonesia
A. celebesensis *A. marmorata* *A. bicolor pacifica*	Population (species composition and identification based on morphology and mitochondrial DNA) 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) Jun Aoyama Daniel Limbong Katsumi Tsukamoto	Indonesia
A. bicolor pacifica	Ecology (early life history and recruitment mechanism) 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) T. Otake D. Limbong 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 *A. japonica* *A. celebesensis*	Ecology (species identification and distribution) 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) O. Tabeta N. Mochioka	Philippines
A. japonica *A. bicolor pacifica* *A. marmorata*	Ecology (species distrubution and composition) 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 N. Mochioka (1988)	Philippines
A. celebesensis *A. marmorata* *A. japonica* *A. bicolor pacifica*	Ecology (species composition and seasonal occurrence) 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) T. Tanimoto T. Takai I. Matsui 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 P.H.J. Castle (1975)	Indonesia
A. bicolor *A. marmorata* *A. celebesensis*	Ecology (species identification, distribution, relative abundance and culture feasibility) 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 *A. bicolor* *A. marmorata* *A. celebesensis*	Aquaculture (prospect of eel industry in the Philippines) 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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