Introduced Aquatic Species for Inland Aquaculture: Boon or Bane?

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Boosting fisheries and aquaculture production is the primary driver for the introduction of aquatic species to inland water bodies. Various records show that a total of 155 fish species, 24 mollusks, 13 crustaceans, 6 reptiles, 1 amphibian, and 6 seaweed species are introduced aquatic species (IAS) in Southeast Asia. The Philippines ranks the highest in terms of number of introductions with 115 different species, followed by Singapore with 95. The bulk of these introductions are freshwater fishes, dominated by representatives from the family Cichlidae (33 species) and Cyprinidae (40 species). Nonetheless, IAS continues to provide tremendous gains in terms of increased production and consequent economic gains for Southeast Asian countries, contributing from 9 to almost 99% of freshwater aquaculture production in the region based on average 2010-2014 data. Despite these, there are well known adverse impacts of species introductions such as their effects on biodiversity, and possible introduction also of new pathogens and diseases. In addition, some of these IAS become well adapted to their new environment to the extent of being classified as invasive. Measures to address these adverse impacts of species introductions in inland waters should be undertaken through careful crafting and implementation of regulations on species introductions; conduct of science-based risk assessment prior to introduction; shift in focus towards culture of commercially important native species; and balancing ecological risk and economic gains through valuation of ecosystem goods and services of inland water bodies.

Aquaculture is seen to address the growing demand for fish which can no longer be addressed solely by capture fisheries. Both mariculture and inland aquaculture had continuously increased in the past decades, with the world inland aquaculture production continuously outpacing mariculture production since the late 1980s. Statistical data in 2012 showed that mariculture production contributed 44.2 million metric tons (MT) to the total aquaculture production while 66.6 million MT came from inland aquaculture. Of this, 92% are fish, 6% crustaceans and the rest comprised mollusks and other species. Inland aquaculture is relatively easy to achieve compared to mariculture and hence, has developed rapidly particularly in developing regions with high poverty incidence like Asia, Africa and Latin America (FAO, 2014).

The Role of Introduced Aquatic Species

As a consequence of speeding up the development of aquaculture to improve fisheries production, introduction of already domesticated species in areas beyond their natural distribution became inevitable. As a result, the number of introductions worldwide has more than doubled recently compared to 30 years ago (Gozlan, 2008), which according to Welcomme and Vidtayanom (2003) could be because of the need to: (1) provide new species that have high productivity or higher market value than the local species, *e.g.* introduction of tilapias in various inland water bodies worldwide; (2) fill a vacant niche, *e.g.* introduction of milkfish, *Chanos chanos* in the largest inland water body in the Philippines, Laguna de Bay, and since milkfish is a phytoplankton feeder and Laguna de Bay is a eutrophic lake with high phytoplankton production, milkfish, a high value commodity can utilize the phytoplankton in the Lake that appear to be underutilized by the native species (Delmendo and Gedney, 1976), although milkfish is a euryhaline marine species native to the marine waters of the Philippines; (3) control pests that are vectors of diseases, *e.g.* the mosquito fish, *Gambusia affinis* has been introduced in many parts of the world to control mosquitoes (Pyke, 2008); control water quality, *e.g.* grass carp has been introduced in water bodies with aquatic weed infestation problems (Pipalova, 2006); and develop aquaculture and fisheries, which is the main driver of aquatic species introduction worldwide (Welcomme, 1988; Naylor *et al*., 2001). The FAO Database of Introduced Aquatic Species (*http://www.fao.org/fishery/dias/en*) cited that the reasons for introduction are predominantly for aquaculture (39%), fisheries (17%), ornamental and accidental (8%), bio-control (6%), and interestingly, 22% are for "other" and "unknown" reasons. This bears out the earlier observations that aquaculture is the driver of a great bulk of introductions of alien species (Welcomme, 1988; Naylor *et al*., 2001). Of these introductions, 76% are "unreported" while 11% are initiated by Governments, 6% by the industry and 4% by individuals, and the rest by other entities. The use of introduced species which had been domesticated, both in their areas of natural distribution and beyond, has become a common practice to fast track the growth of aquaculture in many parts of the world, including Asia. Furthermore, the ease of culture and development of techniques for the propagation and farming of a number of species has made it popular for introduction to wide number of habitats and large number of countries. Indeed, the introduction of non-native species in aquaculture is less a result of natural colonization than their association with lucrative ecosystem services. In fact, the growth of the aquaculture industry has been coupled with the introduction of non-native species.

Asia has experienced multiple introduction and translocation of fish species mainly for aquaculture and to a limited extent

Table 1. Aquatic species introductions in Southeast Asia (data based on FAO DIAS)

Country	Fishes	Mollusks	Crustaceans	Reptiles	Amphibians	Seaweeds	TOTAL
Brunei Darussalam	3	n.d.*	1	n.d.	n.d.	n.d.	**4**
Cambodia	19	2	n.d.	n.d.	n.d.	n.d.	**21**
Indonesia	45	4	1	1	n.d.	1	**52**
Lao PDR	15	n.d.	n.d.	n.d.	n.d.	n.d.	**15**
Malaysia	44	n.d.	1	n.d.	n.d.	n.d.	**45**
Myanmar	20	1	1	n.d.	n.d.	n.d.	**22**
Philippines	76	20	10	3	1	5	**115**
Singapore	86	1	3	4	n.d.	n.d.	**95**
Thailand	39	3	3	3	1	n.d.	**49**
Viet Nam	20	n.d.	n.d.	n.d.	n.d.	n.d.	**20**

n.d.- no data

for stock enhancement (Silva *et al*., 2006). In Southeast Asia a total of 155 fishes, 24 mollusks, 13 crustaceans, 6 reptiles, 1 amphibian, and 6 seaweed species have reportedly been introduced in many ASEAN Member States (AMSs). The Philippines ranks highest in terms of total number of aquatic species introductions with a reported total of 115 different species, next is Singapore at 95 different species, followed distantly by Indonesia and Thailand (**Table 1**). Introduced fish species in the AMSs come from 40 families from 14 orders, with 61 species from the Order Perciformes, dominated by 33 species from Family Cichlidae. This is followed by 40 species from Order Cypriniformes with 37 representatives from the Family Cyprinidae. Of the 150 fish species introduced in the region, 70% are freshwater species while the rest are mostly euryhaline species that can also inhabit freshwater environments (**Table 2**). Admittedly the FAO Dataset for Introduced Aquatic Species (DIAS) is limited compared to what the different countries provided as data from the survey. The data in **Table 2** is supplemented by information obtained from literatures.

Table 2. Introduced species in ASEAN countries, data based on FAO DIAS (*http://www.fao.org/fishery/dias/en*) unless otherwise stated and classification is based on Fishbase (*www.fishbase.org*)

Order, Family, Species	Common name	BR	KH	ID	LA	MY	MM	PH	SG	TH	VN	Habitat*
Anguilliformes, Anguillidae												
Anguilla anguilla	European eel			1								MW;FW;BW
Anguilla japonica	Japanese eel		1			1[f]				1		MW;FW;BW
Atheriniformes, Melanotaeniidae												
Melanotaenia nigrans	black-banded rainbowfish							1				FW
Beloniformes, Adrianichthyidae												
Oryzias latipes	Japanese ricefish					1			1			FW;BW
Characiformes, Characidae												
Gymnocorymbus ternetzi	black tetra									1		FW
Hemigrammus spp.	rummy nose tetra								1			FW
Hyphessobrycon spp.	candy cane tetra								1			FW
Moenkhausia oligolepis	glass tetra								1			FW
Paracheirodon innesi	neon tetra								1			FW
Thayeria obliquus	Penguinfish								1			FW
Characiformes, Serrasalmidae												
Colossoma macropomum	cachama			1				1	1	1[a]		FW
Colossoma sp.	Red pomfret					1[b]						FW
Piaractus brachypomus	Pirapitinga		1	1			1	1				FW
Pygocentrus nattereri	Red-bellied piranha							1				FW
Cypriniformes, Cobitidae												
Chromobotia macracanthus	clown loach									1		FW

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Order, Family, Species	Common name	BR	KH	ID	LA	MY	MM	PH	SG	TH	VN	Habitat*
Misgurnus anguillicaudatus	pond loach				1[a]			1				FW
Cypriniformes, Cyprinidae												
Abbottina rivularis	Chinese gudgeon				1[a]					1		FW
Acheilognathus sinensis	Chinese bitterling				1[a]							FW
Amblypharyngodon chulabhornae									1			FW
Aristichthys nobilis (*Hypopthalmichthys nobilis*)	Bighead carp	1	1	1	1	1	1	1	1	1	1[f]	FW
Aspidoparia morar	Morari			1							1[f]	FW
Barbodes spp.	Barb								1			FW
Barbonymus gonionotus	Silver barb			1		1	1	1	1			FW
Carassius auratus auratus	goldfish			1		1		1	1	1	1[f]	FW
Carassius carassius	cruscian carp							1		1		FW
Catla catla	catla		1			1		1		1	1[f]	FW
Cirrhinus chinensis	mirror carp			1		1			1	1	1[f]	FW
Cirrhinus cirrhosus	mrigal		1[f]		1[f]	1[f]						FW
Cirrhinus molitorella	mud carp			1		1[b]			1	1		FW
Cirrhinus mrigala	mrigal carp		1	1		1		1		1		FW
Ctenopharyngodon idella	grass carp		1	1		1	1	1	1		1[f]	FW
Cyprinus carpio	Common carp	1	1	1	1	1	1	1	1	1	1[f]	FW
Devario malabaricus	Malabar danio						1		1			FW
Esomus metallicus									1			FW
Hemibarbus labeo	Barbel steed				1[f]							
Hemibarbus maculatus	Spotted steed				1[a]							FW
Hypophthalmichthys molitrix	silver carp		1	1		1	1	1	1	1	1[f]	FW
Labeo rohita	Roho labeo		1[f]			1		1				FW
Leptobarbus hoevenii	Hoven's carp							1	1			FW
Megalobrama amblycephala	Wuchang bream							1				FW
Mylopharyngodon piceus	black carp					1[b]		1		1		FW
Osteochilus hasseltii	bonylip barb			1				1				FW
Pseudorasbora parva	Stone moroko				1[a]							FW
Puntius binotatus (*Barbodes binotatus*)	spotted barb			1					1			FW
Puntius conchonius	rosy barb								1			FW
Puntius gonionotus (*Barbonymus gonionotus*)	silver barb			1		1[f]	1	1				FW
Puntius orphoides (*Systomus rubripinnis*)	Javaen barb			1			1					FW
Puntius partipentazona (*Puntigrus paripentazona*)									1			FW
Puntius semifasciolatus (*Barbodes semifasciolatus*)	Chinese barb				1[a]				1			FW

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Puntius spp.	Barbs								1			FW
Puntius tetrazona (*Puntigrustetrazona*)	Sumatra barb								1			
Rasbora borapetensis	Blackline rasbora								1			FW
Rasbora spp.									1			FW
Rasborinus lineatus (*Metzia lineata*)					1[a]							FW
Rasborinus macrolepis (*Metzia mesembrinum*)									1			FW
Tinca tinca	tench			1								FW
Cyprinodontiformes, Aplocheilidae												
Aplocheiluspanchax	blue panchax			1		1						FW
Cyprinodontiformes, Fundulidae												
Fundulus heteroclitus	mummichog							1				
Cyprinodontiformes, Poecillidae												
Gambusia affinis	mosquitofish		1	1	1[f]	1	1	1			1[f]	FW
Poecilia latipinna	sailfin molly			1				1	1	1	1[f]	FW
Poecilia reticulata	guppy			1				1	1			MW;FW;BW
Poecilia sphenops	molly			1		1[b]			1			FW;BW
Poecilia velifera	sailfin molly					1[b]			1	1		FW;BW
Xiphophorus hellerii	swordtail			1				1	1			FW;BW
Xiphophorus maculatus	swordtail			1				1	1			FW
Xiphophorus variatus	swordtail								1			FW
Cyprinodontiformes, Rivulidae												
Austrolebias nigripinnis	Blackfin-pearlfish							1				FW
Lepisosteiformes, Lepisosteidae												
Lepisosteus spatula						1[b]						FW
Mugiliformes, Mugilidae												
Mugil cephalus	flathead grey mullet									1		FW
Osmeriformes, Osmeridae												
Osmerus mordax	rainbow smelt							1			1	MW;FW;BW
Osteoglossiformes, Arapaimidae												
Arapaima gigas	Arapaima					1[b]		1[g]	1	1		FW
Osteoglossiformes, Notopteridae												
Chitala chitala	clown knifefish						1					FW
Chitala ornata	clown featherback							1	1			FW
Osteoglossidae, Osteoglossiformes												
Osteoglossum bicirrhosum	Arawana							1				FW
Scleropages formosus	Asian bonytongue								1			FW
Perciformes, Ambassidae												
Parambassis siamensis	glass fish								1			FW
Perciformes, Anabantidae												
Anabas testudineus	climbing perch			1				1		1		FW
Perciformes, Blenniidae												
Omobranchus elongatus	cloister blenny							1				MW

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Perciformes, Centrarchidae												
Lepomis cyanellus	green sunfish							1				FW
Lepomis macrochirus	bluegill							1				FW
Micropterus dolomieu	smallmouth bass									1		FW
Micropterus salmoides	largemouth black bass					1		1				FW
Pomoxis nigromaculatus	black crappie							1				FW
Perciformes, Channidae												
Channamaculata	blotched snakehead										1	FW
Channa micropeltes	Indonesian snakehead								1			FW
Channa striata	striped snakehead			1				1				FW
Perciformes, Charangidae												
Trachinotus falcatus	snubnose pompano								1			MW
Perciformes, Cichlidae												
Aequiden slatifrons	Platinum acara			1								FW
Amphilophus citrinellus	midas cichlid								1			FW
Amphilophus labiatus	red devil								1			FW
Astronotus ocellatus	Oscar								1			FW
Cichla monoculus						1[b]			1			FW
Cichla ocellaris	peacock cichlid					1[b]			1			FW
Cichlasoma festae	guayas cichlid								1			FW
Cichlaso maoctofasciatum	Jack dempsey									1		FW
Cichlasoma spp.									1			FW
Cichlasoma trimaculatum	three spot cichlid								1			FW
Cichlasoma urophthalmus	mayan cichlid							1[d]	1			FW
Etroplus suratensis	Pearlspot			1		1		1	1			BW; tolerate FW and MW
Geophagus brasiliensis	pearl cichlid							1				FW;BW
Geophagus surinamensis	red striped eartheater								1			FW
Hemichromis bimaculatus	Jewelfish							1				FW;BW
Oreochromi saureus	blue tilapia						1	1	1	1		FW;BW
Oreochromis mossambicus	Mozambique tilapia		1	1		1	1	1	1	1	1[f]	FW;BW
Oreochromis niloticus	Nile tilapia	1	1	1	1	1	1	1	1[a]	1	1[f]	FW;BW
Oreochromis niloticus x Oreochromis mossambicus	hybrid tilapia (Molobicus?)		1	1				1		1		FW;BW
Oreochromis spilurus spilurus	Sabaki tilapia							1				FW;BW
Oreochromis spp.				1				1				FW;BW
Oreochromis urolepis hornorum	Wami tilapia					1[b]		1				FW;BW
Parachromis managuensis	Jaguar guapote							1[e]	1			FW
Pelvicachromis pulcher	rainbow krib								1			FW
Pterophyllum spp.	freshwater angelfish								1			FW

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Sarotherodon galilaeusgalilaeus	Mango tilapia							1				FW;BW
Sarotherodon melanotheron	blackchin tilapia		1[f]					1[d,e]				MW;FW;BW
Symphysodon spp.	Blue discus								1			FW
Thorichthys meeki	firemouth cichlid								1			FW
Tilapia buttikoferi									1			FW
Tilapia rendalli (*Coptodon rendalli*)	redbreast tilapia							1		1		FW;BW
Tilapia zillii (*Coptodon zillii*)	redbelly tilapia					1[b]		1	1	1		FW;BW
Vieja synspila (*Paraneetroplus synspilus*)	redhead cichlid								1			FW
Perciformes, Eleotridae												
Oxyeleotris marmorata	marble goby								1			FW;BW
Perciformes, Gobiidae												
Rhinogobius giurinus						1[b]			1			FW
Rhinogobius sp.					1[a]							FW
Perciformes, Helostomatidae												
Helostoma temminckii	kissing gourami			1		1[b]		1	1			FW
Perciformes, Lutjanidae												
Lutjanus argentimaculatus	mangrove snapper								1			MW;FW;BW
Perciformes, Osphoronemidae												
Betta imbellis	crescent betta					1[f]			1			FW
Betta splendens	siamese fighting fish					1[b]	1		1			FW
Colisa lalia (*Trichogaster lalius*)	dwarf gourami								1			FW
Osphronemus gorami	giant gouramy		1	1			1	1	1	1		FW
Trichogaster leerii	pearl gourami							1				FW;BW
Trichogaster microlepis	moonlight gourami								1			FW
Trichogaster pectoralis	snakeskin gourami			1		1[f]	1	1	1			FW
Trichogaster trichopterus	three spot gourami or blue gourami							1				FW
Perciformes, Percidae												
Gymnocephalus cernuus	ruffe							1				FW;BW
Perciformes, Pomacentridae												
Neopomacentrus violascens	violet demoiselle							1				MW
Perciformes, Sciaenidae												
Sciaenops ocellatus	red drum							1	1			MW;FW;BW
Perciformes, Terapontidae												
Bidyanus bidyanus	silver perch							1[g]				FW
Scortum barco	Jade perch					1[b]						FW
Salmoniformes, Salmonidae												
Oncorhynchus mykiss	rainbow trout			1		1		1		1		MW;FW;BW
Oncorhynchus rhodurus	Japanese amago							1		1		MW;FW;BW
Salmo salar	Atlantic salmon			1				1				MW;FW;BW

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Salmo trutta fario	Sea trout			1				1				MW;FW;BW
Siluriformes, Callichthyidae												
Corydoras spp.	armored catfish								1			FW
Siluriformes, Clariidae												
Clarias batrachus	Philippine catfish			1				1		1		FW
Clarias gariepinus	North African catfish		1	1	1[f]	1	1	1	1	1	1[f]	FW
Clarias gariepinus x C. macrocephalus						1						FW
Clarias macrocephalus	bighead catfish		1	1		1	1[f]				1	FW
Siluriformes, Ictaluridae												
Ameiuruscatus	white catfish							1				FW
Ictalusus nebulosus	American catfish										1[a]	FW
Ictalurus punctatus	channel catfish			1				1		1		FW
Siluriformes, Locariidae												
Hypostomus plecostomus	suckermouth catfish					1			1	1	1[f]	FW; BW
Hypostomus spp.				1						1		FW; BW
Liposarcus pardalis (Pterygoplichthys pardalis)	Amazon sailfin catfish							1	1		1[c]	FW
Pterygoplichthys disjunctivus	Vermiculated sailfin catfish					1[b]		1[e]				FW
Pterygoplichthys spp.	armored catfish									1		FW
Siluriformes, Pangasiidae												
Pangasius hypophthalmus	striped catfish						1[f]	1				FW
Pangasius pangasius	Pangas catfish		1	1					1	1	1[f]	FW
Synbranchiformes, Syngbranchidae												
Monopterus albus	Asian swamp eel							1[e]	1[f]			FW

* ***BW***- *brackishwater;* ***FW***-*freshwater:* ***MW***-*marine waters*
BR-*Brunei Darussalam;* ***KH***-*Cambodia;* ***ID***-*Indonesia;* ***LA***-*Lao PDR;* ***MY***-*Malaysia;* ***MM***-*Myanmar;* ***PH***-*Philippines;* ***SG***-*Singapore;* ***TH***-*Thailand;* ***VN***-*Viet Nam*
Sources: *a - Welcomme and Vidthayanom (2003); b - Rahim* et al. *(2013); ; c - Levin* et al. *(2008); d - Ordoñez* et al. *(2015); e – Guerrero (2014); f - Fishbase; g - personal observation by the author*

Beneficial Impacts of IAS to Fisheries and Aquaculture

Positive impact of fisheries and aquaculture in the livelihood of fishers and fish farmers has been amply demonstrated. Six of the top ranked 22 species in freshwater aquaculture in the world have more than 20% of their production coming from areas outside of their natural range of distribution. In 2000-2004, about 16% of global fish production from aquaculture is from alien freshwater species (Silva *et al*., 2009). From 2010 to 2014, introduced aquatic species (IAS) significantly contributed to the freshwater fish production in the AMSs. **Table 3** shows the average contribution of IAS to total aquaculture production as well as solely to freshwater aquaculture production. In the Southeast Asian region, aquaculture of IAS contributes about 23% to its total aquaculture production and more than 47% to the total freshwater aquaculture production. In Cambodia, about 67% of total aquaculture production comes from freshwater IAS. In freshwater aquaculture, the Philippine production ranks first in terms of contribution from IAS with close to 99%. Data for the Philippines includes milkfish production in inland waters since milkfish, although native to marine waters is considered an introduced species in inland water bodies. Keeping track of introductions by country is quite a challenge for the Mekong River Basin since jurisdiction is shared by several member states. In general, IAS in freshwater aquaculture contribute about 50% to total freshwater fisheries production of five AMSs, *i.e.* Cambodia, Malaysia, Philippines, Singapore, and Thailand. As in previously stated, both the Philippines and Singapore had the highest number of IAS. Vietnam and Brunei Darussalam had much lower contribution at just 28% and 19%, respectively. Viet Nam's production of its native pangas catfish in freshwater contributes on the average 50% to total freshwater aquaculture production.

Table 3. Contribution of introduced species to freshwater aquaculture production of AMSs in relation to total production and freshwater fisheries production (values are averages for the period 2010-2014 computed from FAO FishStatJ (*http://www.fao.org/fishery/statistics/ software/fishstatj/en*))

Country	Total aquaculture productiona (MT)	Total freshwater aquaculture productionb (MT)	Total freshwater aquaculture production of IAS (MT)	Contribution to total aquaculture production of IAS (%)	Contribution to freshwater aquaculture production of IAS (%)
Brunei Darussalam	570.38	17.64	3.41	0.6	19.3
Cambodia	83,211.00	80,063.00	56,246.00	67.6	70.3
Indonesia	3,303,182.60	2,120,915.58	681,008.92	20.6	32.1
Lao PDR	99,191.00	99,191.00	28,160.00	28.4	28.4
Malaysia	301,764.77	136,576.63	71,768.00	23.8	52.5
Myanmar	888,804.35	826,648.19	77,702.26	8.7	9.4
Philippines	908,546.60	308,673.00	305,143.20	33.6	98.9
Singapore	4,258.94	516.45	417.54	9.8	80.8
Thailand	1,138,390.09	425,984.29	220,323.80	19.4	51.7
Viet Nam	3,040,907.80	2,295,301.80	642,333.00	21.1	28.0
TOTAL	**9,768,827.52**	**6,292,035.80**	**2,083,106.13**	**23.4***	**47.1***

a *- Excluding seaweeds;* ***b*** *- excluding production of euryhaline IAS in marine and brackish waters; *average for the region*

The common carp, *Cyprinus carpio* is one of the first species introduced to all AMSs although aquaculture production records had shown that this commodity has not contributed significantly to the region. Among the early record of common carp introduction to the Philippines was in 1915 with the release of this species from Hong Kong in Lake Lanao in Mindanao (Villaluz, 1966; Escudero, 1994). However, this species did not thrive well and are now considered nearly decimated in this Lake. Another cyprinid which has grown in importance to freshwater aquaculture in a number of AMSs is the bighead carp, *Aristichthysnobilis* spp. In the Philippines, this species was introduced from Taiwan in 1968 (Guerrero, 2014) and is now among the top commodities cultured in Laguna de Bay, the country's largest inland water body. Other ASEAN countries that reflect this species in the FAO aquaculture production data are Brunei Darussalam, Cambodia, Lao PDR, Malaysia, Myanmar, and Singapore.

The tilapias are tropical to subtropical species native to Africa and the Middle East. Due to its relative ease to domesticate and culture, a number of species of tilapia has been introduced in various parts of the world. Of the various species of tilapias that have been introduced in the AMSs, Nile tilapia, *Oreochromis niloticus* is the species common to all. Since the 1980s nearly all worldwide introduction of tilapia is for aquaculture (Canonico *et al*., 2005). Unlike the common carp which is one of the species with earliest records of introduction, production of tilapia continues to contribute significantly not only to freshwater but also brackishwater culture as well (**Fig. 1**). Millions of dollars have been invested, in improving breeds of tilapia for better production traits, particularly for the Nile tilapia, *Oreochromis niloticus*. Among the most well-known ones are the Genetically Improved Farmed Tilapia or GIFT (Ponzoni *et al*. 2011), and the Genetically Male Tilapia or GMT (Mair *et al*., 1995), among others. Tilapia production in the AMSs contributed 43% to world's total tilapia production based on average for the period 2010-2014. The contribution of tilapia aquaculture in the different AMSs, averaged from FAO reported values from 2010 to 2014, is shown in **Tables 4** and **Table 5**. Tilapias contribute as much as 25% both to total aquaculture and freshwater aquaculture production in Lao PDR given that this country has only inland resources. In terms of contribution to total aquaculture production in the AMSs, tilapia only contributes 6.7% in volume and just 2.1% in value. However, in terms of total freshwater aquaculture

Fig. 1. Harvest of Nile tilapia from fish cage in Lake Bato, Camarines Sur, Philippines

Table 4. Contribution of tilapia production to total aquaculture production of AMSs from FAO FishStatJ data (values are averages from 2010-2014 of tilapia production in marine, brackish and freshwater)

Country	Total tilapia volume (MT)	Total tilapia value ('1000 US$)	Contribution to total volume of aquaculture (%)	Contribution to total value of aquaculture (%)
Brunei Darussalam	3.88	18.21	0.7	0.1
Cambodia	2,360.00	3,540.00	2.8	0.5
Indonesia	721,011.53	1,261,717.40	7.0	2.9
Lao PDR	24,816.00	37,032.78	25.0	5.0
Malaysia	43,454.75	95,933.31	7.8	2.3
Myanmar	43,677.78	41,700.60	4.9	0.6
Philippines	43,677.78	414,112.89	1.8	4.0
Singapore	48.41	174.21	1.1	0.2
Thailand	184,863.00	280,141.47	16.2	1.8
Viet Nam	190,110.20	268,353.12	6.2	0.8
TOTAL	**1,254,023.33**	**2,402,724.00**	**6.7***	**2.1***

Note: *comparison to total production only uses data for aquatic animals and excludes seaweeds; *average for the region*

Table 5. Freshwater (FW) tilapia production in AMSs and its contribution to FW aquaculture both in volume and value (values are means from annual production from 2010 to 2014) from FAO FishStatJ data

Country	Total volume of FW aquaculture (MT)	Total value of FW aquaculture ('1000US$)	Total volume of tilapia production in FW (MT)	Total value tilapia production in FW ('1000US$)	Volume contribution of tilapia in FW aquaculture (%)	Value contribution of tilapia in FW aquaculture (%)
Brunei Darussalam	17.64	91.58	3.11	18.11	17.6	19.8
Cambodia	80,063.00	138,068.50	2,360.00	3,540.00	2.9	2.6
Indonesia	2,119,063.81	3,781,539.88	677,548.06	1,191,765.64	32.0	31.5
Lao PDR	99,191.00	148,023.68	24,816.00	37,032.78	25.0	25.0
Malaysia	136,576.63	270,585.13	42,221.26	92,649.34	30.9	34.2
Myanmar	826,648.19	1,158,200.74	42,710.40	40,667.96	5.2	3.5
Philippines	308,673.00	478,620.16	245,557.60	389,652.53	79.6	81.4
Singapore	516.45	2,637.48	48.41	174.21	9.4	6.6
Thailand	425,984.29	759,379.26	184,863.00	280,141.47	43.4	36.9
Viet Nam	2,295,301.80	4,308,533.60	190,110.20	268,353.12	8.3	6.2
TOTAL	**6,292,035.80**	**11,045,680.00**	**1,410,238.03**	**2,303,995.17**	**22.4***	**20.8***

**average for the region*

production, tilapias contribute significantly to the region's aquaculture production at 22.4% in volume and 20.8% in value. The importance of tilapia in each country varies with the Philippines having the highest contribution of tilapias at almost 80% in volume (almost 246 thousand MT) and more than 81% in value (at almost US$ 390 million).

For the AMSs, it is without a doubt that IAS has greatly contributed to production and the economy of the region. As mentioned previously, inland freshwater aquaculture is relatively more accessible to poorer communities than mariculture as it entails less initial start-up costs. Indeed, one can start with a small cage in an inland water body, and expand the operations as more capital becomes available. Another benefit of introduction is for the enhancement of natural water bodies. Even native fish species are not immune from being introduced to other bodies of water where they are not part of the native population. The translocation of native species from one drainage system to another in the same country is a widely accepted method for enhancement of many natural waters around the world (Innal & Erk'akan, 2006). In the Philippines, the endangered tiny goby *Misthichthys luzonensis*, indigenous to Lake Buhi in Camarines Sur, Philippines, has been translocated to another adjacent water body, *i.e.* Lake Manapao which serves as sanctuary (Soliman, 1994). Translocation may be a way of enhancing fisheries productivity, an example of which is the intentional introduction of milkfish *Chanos chanos* in Laguna de Bay, Philippines for the fish pen culture industry. Milkfish is a marine species but with euryhaline characteristics that enable it to be cultured in a variety of aquatic environments, from marine cages to brackishwater ponds to freshwater fish pens (Bagarinao, 1999). The commodity is continuously being produced in a wide range of culture environments, including other lakes in the country because this is a preferred food fish for Filipinos.

Adverse impacts of IAS

Impact on Biodiversity

Introduction and/or translocation of aquatic organisms primarily affect biodiversity in localities of introduction. IUCN (1999) cited that introduction of exotic species is the second leading cause for the loss of biodiversity, after habitat destruction. There are examples of invasive species altering the evolutionary pathway of native species by competitive exclusion, niche displacement, hybridization, introgression, predation, and ultimately extinction (Mooney and Cleland, 2001). Moreover, introduced invasive species are considered the second leading cause of species extinction and endangerment worldwide, after habitat destruction (Williams *et al*., 1989).

Introduced species have far reaching adverse impacts, as in the case of the golden apple snail *Pomacea canaliculata* whose introduction was as alternative protein source for Filipinos. Its introduction to the country has been blamed for the loss of the edible native snail *Pila luzonica* (Pagulayan, 1997). The loss of most of the endemic cyprinids of in Lake Lanao, the third largest lake in the country, has been attributed to the introduction of the white goby *Glossogobius giurus* and the eleotrid *Hypseleotris agilis* (Juliano *et al*., 1989). Furthermore, the introduction of the walking catfish *Clarias batracus* has resulted in the loss of the native bighead catfish *Clarias macrocephalus* in many inland water bodies in the country. Thus, the Philippine-based SEAFDEC Aquaculture Department (AQD) had been implementing R&D activities to breed *C. macrocephalus* (Tan-Fermin *et al*., 2008) in the hope of restocking depleted inland water bodies but difficulties in obtaining wild broodstock for the induced spawning activities has hampered AQD's efforts.

Comparison of the fish biodiversity in an aquaculture and non-aquaculture site in Laguna de Bay of the Philippines, which widely used for fish production, showed that fish biodiversity was significantly lower in the aquaculture site compared to the non-aquaculture site. There was a significantly higher predominance of introduced species for culture (Nile tilapia, bighead carp, and Tra catfish) compared to native species in the aquaculture site. The non-aquaculture site had significantly higher relative dominance of native species. Indices of biodiversity, such as Shannon-Wiener Index, Simpson index and Evenness, all indicate significantly higher fish biodiversity in non-aquaculture sites (Cuvin-Aralar, 2014; 2016). In the same lake, historical fish production records show that prior to aquaculture activities (with introduced species such as milkfish and tilapia) in the 1960s, 70% of fish catch in the lake comprised mainly of native species such as silver therapon (*Leiopotherapon plumbeus*), white goby (*Glossogobius giurus*), Manila sea catfish (*Arius* sp.), and native catfish (*Clarias macrocephalus*). These same species contributed only 52% a few years after the introduction of aquaculture by 1970s (Delmendo, 1987). This native species were further diminished to just 6.4% of the catch in a localized area used for aquaculture of introduced species (Cuvin-Aralar, 2014; 2016).

Extirpation of native species from introduced species, especially those that are considered invasive, could be mainly due to competition, predation, habitat degradation, and alien pathogens and parasites (Gurevitch and Padilla, 2004; Gozlan, 2010).

Introduction of new pathogens and diseases

Translocation of animals is always associated with significant risks of transmission of pathogenic organisms (Leighton, 2002). Apparently, the healthy Pacific white shrimp, *Litopeneus vannamei* introduced to Asian countries from unreliable sources has resulted in the spread of the Taura syndrome virus (TSV). Taiwan and later Thailand experienced this TSV outbreak in 2003 which affected not only *L. vannamei* population but also that of the local black tiger shrimp *Penaeus monodon* (Phalitakul *et al*., 2006).

Genetic impact of introduced aquatic species

Species introductions also have genetic impacts. This concern is often neglected because it is more difficult to assess than the other more overt impacts of introductions. Hybridization and introgression are among the impacts, where hybridization occurs if individuals of two genetically distinct individuals interbreed, regardless of taxonomic class (Harrison, 1993). Introgression occurs from backcross of hybrids with either or both parents. Although hybridization is said to result in hybrid vigor for hybrids of genetically closely related population, the reverse may be true for hybrids of genetically distant populations. In this case hybridization may result in reduced fitness (Nguyen and Na-nakorn, 2004). In Thailand, the native catfish *Clarias macrocephalus* is the preferred species but due to its slow-growth, it was hybridized with the North African catfish *Clarias gariepinus*. Escaped hybrid catfish from crosses between female *C. macrocephalus* and male *C. gariepinus* were shown to interbreed with wild population of *C. macrocephalus*. Wild *C. macrocephalus* had been found to have hybrid genotypes. The use of introgressed *C. macrocephalus* as broodstock in producing hybrids with *C. gariepinus* by fish farmers threaten the loss of hybrid vigor for growth and disease resistance (Senanan *et al*., 2004). In the natural environment, hybridization does occur but greater risks are posed when native population hybridizes with introduced species due to potential loss of adaptive characteristics, *e.g.* timing of migration and ability to locate natal streams may be lost in the host (native species). Another possibility is the hybrid becomes more successful than the original native species wherein the later will become lost through competition (Welcomme and Vidthayanon, 2003).

IAS as Invasive species

Although many introduced species have negligible effects on native biodiversity, there are a few that will become invasive and have adverse ecological effects (Britton *et al*., 2011). Among the characteristics of an introduced species becoming invasive is a rapid adaptation to new environment. Genetic studies show that it takes 20 generations or less for a new species to adapt to novel environments indicative of the role of evolutionary processes in invasiveness of a species (Prentis *et al*., 2008). The invasive species then achieve "pest" status if this species has no appreciable socioeconomic value (Britton *et al*., 2011). Escapees from the ornamental fish trade like the South American sucker mouth catfish, also known as janitor fish *Pterygoplichthys pardalis* and *P. disjunctivus*, have become invasive in many areas in Luzon including Marikina River and Laguna de Bay (Chavez *et al*., 2006; Jumawan *et al*., 2011) and Agusan Marsh in Mindanao (Hubilla *et al*., 2008). The fish (**Fig. 2**) with its hard armor-like covering inflicted damage to the banks of the Marikina River due to is burrowing habit and damaged the aquaculture fish cages in Laguna de Bay. Considerable expense has been incurred from a "bounty system" type of approach to eradicate janitor fish wherein fishers were paid to catch the janitor fish at PhP5.00/kg, after which the caught fish are destroyed (Joshi, 2006). The fish is considered invasive since it is not considered a food fish, in addition to the aforementioned damage it has been causing. **Fig. 2** shows the janitor fish catch in a fish trap in Laguna de Bay, Philippines. This fish constituted an average relative dominance of 10.4 % and a peak of 64.0% in the Lake, based on catch data from fish traps set in the Lake from 2013 to 2015 (Cuvin-Aralar, 2016).

Fig. 2. South American sucker mouth catfish or janitor fish caught in fish traps in Laguna de Bay, Philippines

The clown featherback *Chitala ornata*, also known as knifefish in the Philippines has also become invasive in Laguna de Bay (**Fig. 3**). The fish was introduced in the country for the ornamental fish trade, although in its native range in mainland Asia, it is considered a food fish. Its introduction in the Philippines was thought to be accidental from lakeshore ponds damaged by typhoons. Fish pen and fish cage owners have complained of severe predation of their cultured milkfish and tilapia by the clown featherback when the fish inadvertently enter their cages, resulting in poor harvest. Open water fishers also complain that their catch is being dominated by the clown featherback, in place of the more valuable commodities. Indeed, the claim has been backed by recent findings that this fish had a mean relative dominance of 4.5% and a peak of 68.0% from 2013 to 2015, from fish trap catch data (Cuvin-Aralar, 2016).

Fig. 3. Juveniles of clown featherback caught in fish traps in Laguna de Bay, Philippines

As mentioned in the foregoing, among the top freshwater species being farmed in the region is an introduced species, the Nile tilapia *Oreochromis niloticus*. Although many countries have accepted this species as an important aquaculture commodity, there are those that consider the introduction of this species as a nuisance and considered an invasive species (Linde-Arias *et al*., 2008; Angienda *et al*., 2011). Another cichlid, the black chin tilapia *Sarotherodon melanotheron* and the Mayan cichlid *Cichlasoma urophthalmus* introduced in freshwaters in the Philippines has now spread to brackish and marine waters of the country (Ordoñez *et al*., 2015). These two species had successfully adapted way beyond their area of original introduction.

Way Forward

Regulation and Enforcement

The SEAFDEC Regional Guidelines for Responsible Aquaculture in Southeast Asia (Platon *et al*., 2005) includes Article 9.3 on the use of aquatic genetic resources for aquaculture and culture-based fisheries. Under this article, are provisions on introduction of aquatic organisms, *i.e.* "States should recognize the potentially serious impact of introduced species on the local aquatic biodiversity"; and "States should consider a total ban on the introduction of species shown by appropriate risk assessment to be detrimental to local ecosystems." The Guidelines had been formulated and consolidated in consultation with the AMSs and its adoption should be enforced by the countries. Prior to the publication of the aforementioned Regional Guidelines, some AMSs have already in place limited provisions on introduction of aquatic species.

In the Philippines for instance, the Bureau of Fisheries and Aquatic Resources (BFAR) had issued Fisheries Administrative Order 189 series of 1993 prohibiting the importation of live shrimp and prawn of all stages. However, this ban was lifted to favor the culture of the Pacific white shrimp *Penaeus vannamei* through Fisheries Administrative Order 225, 225-1 series of 2007, and Fisheries Administrative Order 225-2, 225-3 series of 2008. This was meant to address the demand for the entry of this shrimp into the country to save the ailing tiger shrimp (*Penaeus monodon*) that has been devastated by various diseases. Although no other Fisheries Administrative Orders had been issued by BFAR prohibiting the introduction of other species for aquaculture in either the food or ornamental fish industry, it had issued numerous Fisheries Administrative Orders through the years mainly prohibiting or regulating the export of various fisheries commodities as well as establishing fish sanctuaries in various parts of the country. Such regulations should be revived and strictly imposed, and made imperative as aquaculture continues to expand.

Other non-ASEAN countries have in place approaches that strictly regulate exotic introductions, for example, New Zealand has the Hazardous Substances and New Organisms Act (1996) which other countries could follow, as the Act is a comprehensive legislation with clear oversight, especially in terms of exotic introductions, where importers of non-native species must apply to an independent regulatory authority accountable to the country's Environment Ministry and Parliament for public approval (Naylor, 2001). It is a case of guilty until proven otherwise. Thus, all species are considered potentially invasive and therefore entry is prohibited unless proven otherwise.

Risk Assessment

It would be difficult to enforce guidelines and regulations on entry of alien species if there is no clear assessment of risks. Assessment of the potential risk of an alien species should be among the first line of defense against unwarranted effects of introduced species. The Convention on Biological Diversity Biosafety Protocol (also known as the Cartagena Protocol) states that risk assessment should be carried out in a scientifically sound manner, taking into account recognized risk assessment techniques (CBD, 2000: *https://www.cbd.int/doc/legal/cartagena-protocol-en.pdf*). Risk assessment for invasive species is for the purpose of implementing two classes of risk management decisions, *i.e.* introduction of potentially invasive non-native species, their vectors, or conveyances prior to establishment; and decisions regarding the allocation of scarce resources for the control of established invasive species, including rapid response to emerging threats (Andersen *et al*., 2004). In the first case, result of risk assessment would lead to decisions whether to authorize or permit introduction under specified conditions. The second case would involve efforts to address problems and issues after introduction of the invasive species. Appropriate risk management ensures that strategies implemented are commensurate with the level of risk posed by non-native species in the environment (Britton *et al*., 2010). There are some risk management tool available to assess the potential invasiveness of non-native freshwater fishes, such as the FISK (Fish Invasiveness Scoring Kit) which is useful in aiding decision- and policy-makers in assessing and classifying freshwater fishes based on their potential invasiveness (Copp *et al*., 2009).

Focus on Culture of Native Species

Aquaculture in the Southeast Asian region as well as the rest of the world has been largely dependent on introduced species. Reducing the dependence on alien species for aquaculture, and focusing on the domestication of commercially important native species, is the most appropriate means of facilitating the expansion of the industry without the accompanying risks of species introductions (Ross *et al*., 2008). However, this move will have to be supported by the Governments, considering that shifting focus to inland native species with high consumer preference but remain largely unstudied, *e.g.* in terms of biology and culture potential, will require huge investments in time, personnel, and funds. This should follow a research and development track taken by popularly cultured commodities such as tilapias. The Mekong River Commission (MRC) implemented the Aquaculture of Indigenous Mekong Fish Species Project (AIMS) and has undertaken research in Lao PDR on six indigenous fish species, and the results showed the potential for producing fish fingerlings on farms (Hortle *et al*., 2013).

Balance between Ecological Risk and Economic Gains

There is growing populatity in the wholistic approach to the valuation of ecosystem goods and services (Bateman *et al*., 2011) as opposed to valuing an ecosystem, in this case inland waters, based only on its aquaculture and fisheries output. When monetary value is placed on the total ecosystem services provided by inland waters, the realization can be achieved that it provides much more than fishery resources but other goods and services as well, *e.g.* water supply, recreational value, and the incentive for more sustainable development (inclusive of aquaculture and fisheries *vis-à-vis* introduced species). In the aquaculture sector, a model was created for the accounting price of the habitat services provided by a mangrove ecosystem to a shrimp population (Mäler *et al*., 2008). Similar valuation could also be done for inland water bodies. Admittedly, the concept of wealth accounting and valuation of ecosystem services still has much room for improvement and development. Nonetheless, attempts to calculate the value of environmental services can provide insights into the tradeoffs between market activity and environmental quality that are implicit in the process of economic growth (Howarth and Farber, 2002).

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