Aquaculture and aquarium industries as sources of invasive species in aquatic ecosystems in Sri Lanka

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Introduction of species beyond their natural range has been cited as one of the most pervasive and ecologically damaging human activities (Carlton, 2001; Brown and Sax, 2004). The threat of introduced invasive species on biodiversity is considered second only to that of habitat loss and degradation (Wilcove *et al*., 1998; Kolar and Lodge, 2001; Olden *et al*., 2004). These species create serious management issues with regard to conservation and sustainable use of global, regional and local biodiversity, with significant undesirable impacts on the goods and services provided by ecosystems (Ruesink, 2005). Their impacts are severe in biogeographical islands as they modify the colonization to extinction equilibrium. Sri Lanka being an island with a rich biodiversity the threat of invasive species should be given a considerable attention.

According to the national list of invasive alien fauna, 08 invasive species out of 12 found in Sri Lanka are aquatic (Marambe *et al*., 2011). The introduced aquatic fauna, in many instances, have been proven to have a strong impact on native populations, leading to their extinction (Minckley *et al*., 2002). The introduction of Nile Perch (*Lates niloticus*) into Lake Victoria has caused the extinction of more than 200 species of endemic native Cichlids through direct predation (Welcomme, 1988). The introduction of Oscar (*Astronotus ocellatus*) and Red Piranha (*Pygocentrus nattereri*) to the north east and south east of Brazil has caused the disappearance of some native fish species and the reduction of young individuals in many others (Minckley *et al*., 2002). In South Africa, around 14 freshwater fish species are believed to be threatened by introduced species. However, out of 1408 global fish introductions, the impact of 73% on native communities is yet unknown (Ruesink, 2003).

The gravity in introducing aquatic species into the environment in Sri Lanka increases as more than 50% of the 91 freshwater fish species in the country are endemic (Pethiyagoda *et al*., 2012) while 10 species are considered globally threatened and 40 species have been identified as nationally threatened (IUCN, 2014) E.g. *Dawkinsia srilankensis*, *Devario pathirana*, *Garra ceylonensis*, *Labeo fisheri*, *L. lankae*, *Laubuca insularis*, *L. ruhuna*, *Pethia bandula*, *Rasbora wilpita*, *Systomus asoka*, *S. martenstyni*, *Lepidocephalichthys jonklaasi*.

It is important to note that aquatic organisms have been intentionally introduced to Sri Lanka in order to enhance commercial and sport fisheries, ornamental fish culture and for ecological management (e.g. bio control agents). According to the FAO Database on the Introduction of Aquatic Species (FAO, 2014), 22 fish species have been introduced to Sri Lankan freshwaters mainly for purposes of aquaculture (Table 1). All of these 22 species introduced to Sri Lanka have not become harmful to the natural environment and some species even could not maintain a viable population in the natural environment (E.g. *Danio rerio, Puntius gonionatus*). Out of all intentionally introduced species only five species (23%) have well established, breeding populations in the aquatic habitats of the country.

The first recorded alien fish introduction to Sri Lanka took place in the 1880s when the rainbow trout (*Oncorhynchus mykiss*) was introduced to the up country streams

during the colonial period in order to enhance sport fishery. The rainbow trout presently inhabits the Horton Plain wildlife reserve. Since then, further range expansion of this fish has not been recorded. The restricted distribution of the rainbow trout may be related to its specific habitat requirements. These introduced fish only become established and spread when the hydrologic regime fits in with their life cycle (Fausch *et al*., 2001). The Horton Plain wildlife reserve is also known to be the habitat of the endemic shrimp *Caridina singhalensis* (Benzie and De Silva, 1988). The rainbow trout feeds on aquatic macro invertebrates and its presence may have affected the populations of the endemic shrimp as well as other endemic crabs in streams.

The common name ‗tilapia' refers to a group of tropical freshwater fish in the family Cichlidae (*Oreochromis*, *Tilapia* and *Sarotherodon* spp.), indigenous to Africa and the southwestern Middle East. Since the 1930s, tilapias have been introduced intentionally worldwide for the biological control of aquatic weeds, as baitfish to certain capture fisheries, for aquaria, and as a food fish. They have been promoted as an important source of protein for Sri Lankans since 1952 by government institutions that have been responsible for the development of inland fisheries. According to Canonico *et al*. (2005) tilapia species exist under wild conditions in every nation in which they have been cultured or introduced, and Sri Lanka is not an exception. Their wide environmental tolerances, trophic adaptability (Ehrlich, 1988), rapid reproduction with maternal care, and the ability to successfully compete with native fish through aggressive behaviour predispose tilapias for success as invasive species in introduced new habitats (Pe´rez *et al*., 2006). Eventhough tilapias are generally considered herbivores, detritivores, or planktivores, they have been documented to consume the eggs and larvae of other fish species, and even small fish (de Moor *et al*., 1986; Arthington *et al*., 1994; Goudswaard *et al*., 2002). According to Pe´rez *et al*. (2006) *O. mossambicus* was responsible for the disappearance of some native fish species in Venezuela (Pullin *et al*., 1997; Canonico *et al*., 2005). The National Aquaculture Development Authority (NAQDA) still promotes tilapia culture in Sri Lanka (MFARD, 2013). Research studies are warranted to investigate the environmental impacts of tilapia introductions on native communities in the country.

The impacts of introduced mosquito fish (*Gambussia* spp.) on wild fish species have been shown by Meffe (1985) and Galat and Robertson (1992). The mosquito fish had a detrimental effect on other fish populations as a result of predation (on fish eggs or fry), competition for limited resources, or a combination of factors (Lydeard and Belk, 1993). The impact of this fish species on the local biodiversity has not yet been investigated in Sri Lanka.

At present, over 150 species that have invaded the natural ecosystems in the world have been documented to come from aquariums and aquatic ornamental culture (Padilla and Williams, 2004). Accidental releases of these species have become one of the top five pathways for the introduction of invasive species (Ruiz et al., 1997) and in most cases they are more environmentally damaging than intentional introductions. Fish that are outgrown in aquaria are also released into natural environment which is considered as a more humane method of disposal of unwanted pets. The ornamental fish industry in Sri Lanka annually imports hundreds of fish species. Live fish exported to Sri Lanka in the year 2010 was 24MT and it increased up to 73MT in 2012 (Figure 01).

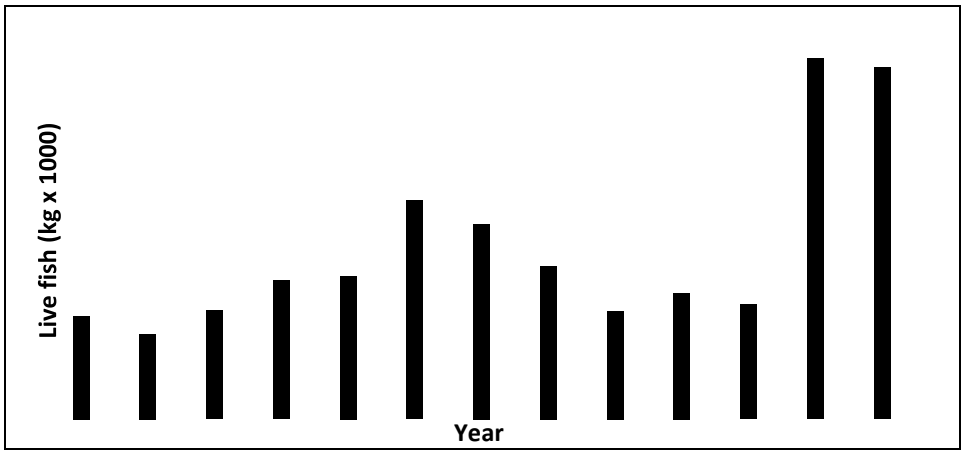

Figure 01. Live fish exports to Sri Lanka from 2000 to 2012 (Fact fish, 2014)

Table 2 presents the list of introduced ornamental aquatic species that are known to spread rapidly in the freshwater ecosystems of the country. These introduced species have expanded their ranges by moving through canals and other aquatic connections created for irrigation and storm water drainages. Some of the aquarium fishes recorded as invasive such as red bellied piranha, *Pygocentrus nattereri* (Readsrilanka, 2014) have not well established wild populations or the exact locations they are found are unknown.

The South American sailfin catfish, popularly known as sucker mouth catfish, tank cleaner or scavenger fish is the most rapidly spreading ornamental fish species that has been accidently introduced into the natural environment of the country. The earliest identification of this fish as *Plecostomus* catfish in Sri Lanka is obviously an incorrect identification since *Plecostomus* has not been recognized as a valid generic name since the 1960s (Fishbase, 2014). Other reports of *Hypostomus* sp. (Bambaradeniya *et al.*, 2006; Silva and Kurukulasuriya, 2010) are also incorrect identifications, since this species group was removed from *Hypostomus* due to their more dorsal-fin rays (Weber, 1992). Catfishes in Family Loricariidae with 10 or more dorsal fin rays are classified under the genus *Pterygoplichthys* and are referred to as sail fin catfishes (Page, 1994; Page and Robbins, 2006).

The key distinct characteristics among the most similar *Pterygoplichthys* species are as follows: *P. multiradiatus* has discrete dark spots on the lateral and caudal peduncle, never coalescing; *P. pardalis* has dark spots on the lateral and caudal peduncle coalescing, with ventral spots mostly discrete; and *P. disjunctivus* has dark spots on the lateral and caudal peduncle coalescing, while ventral spots coalesce to form vermiculations (Figures 2, A & B). According to the morphometric and meristic characteristics and body colouration, fish occurring in freshwater habitats in Sri Lanka could be identified as *P. pardalis* and *P. disjunctivus* (Epa and De Silva, 2013) or their hybrids as suggested by Wu *et al*. (2011).

The sail fin catfish has shown adaptations to flourish in comparatively unpolluted environments (Perennial reservoirs in the Eastern, North central, North western and Central provinces, Kalu River, Attanagalu Oya-upper reach, Deduru oya), as well as highly polluted environments (Hali Ela in the Central province, Eriyawetiya and Bellanwila-Attidiya marshes in the Western province). The sailfin catfishes have also invaded the Dutch canal which is a brackish water body that is connected to the Negombo estuary. The diet of this fish reflects characteristic omnivorous feeding habit by having

wide spectrum of food items ranging from plankton, plant matter to invertebrates showing high feeding plasticity (Hoover *et al*., 2004; Wijetunga and Epa, 2011). Feeding generalists with high adaptability of varied environmental conditions are more successful in invading new habitats (Lodge, 1993; Ruesink, 2005). The sailfin catfishes lay eggs in burrows dig in the stream banks and presumably this beaviour increases the survival of individual young and reduces dispersal into unfavourable environments. This burrowing behavior has contributed to problems with siltation in Pinga Oya, in Kandy. In addition, the burrows potentially destabilize the banks, leading to an increased rate of erosion.

This fish has already negatively affected the existing fishery in the Bolgoda lake, Kala wewa, Kaudulla reservoir, Hurulu wewa, Minneriya reservoir, Parakrama samudraya, Polgolla reservoir, Sorabora wewa, Ulhitiya reservoir, Victoria reservoir mainly by increasing their proportion in the fish catch and by significantly damaging the fishing nets. The fish yield ratio between sail fin catfishes and other fish species in the Nawayalathenna fish landing site at Polgolla reservoir was 3 : 1 in 2012. Fishing nets damage due to entanglement of different sizes of sail fin catfishes in the Polgolla reservoir varied from 320 - 880 cm^2/net/day (Epa and Bandara, 2009). The Sail fin catfishes that get caught in the nets are presently thrown back into the water as there is no demand for this fish in the market as a food fish.

The Golden apple snail (*Pomacea canaliculata*) is a notorious rice pest in other Asian countries like Malaysia, Thailand and Indonesia. Fortunately, the snail species found in Sri Lanka has been identified as *P. diffusa* (Cowie, 2003; Figures 3, C & D) and it has not been recorded in the rice fields of the country. This snail is known to feed on aquatic plants (Kumara *et al*., 1999). Sri Lanka exports a number of freshwater ornamental plants (Ruffled sword plant, *Aponogeton*, Fanwort, *Cabomba*, Hornwort, *Ceratophyllum*; *Cryptocoryne*, Water wisteria, *Hygrophila*, False loose strife, *Ludwigia*, Common eel grass, *Vallisnaria*), which earns most important foreign exchange to the country. Even though this snail has not done any economical damage to the rice farming, it might significantly affect the aquatic ornamental plant industry in future. Apple snails have recently expanded its range from low country wet zone to up country wet zone. Their populations in the urban areas of Matara and Galle districts were not observed after the tsunami in 2004.

The Spotted Gar (*Lepisosteus oculatus*, Figure 3-E) is a fish native to the United States of America, Mexico and Canada and is a voracious feeder of fish and other aquatic organisms (Diana, 1995). In November 2012, fishermen accidentally caught one specimen of spotted gar in Handapanagala wewa, Moneragala. This observation exemplifies the alarming situation of increasing accidental introductions of fish species into the freshwaters of Sri Lanka. If there is a breeding population of spotted gar in Handapanagala reservoir, it may impose a direct threat to the existence of other aquatic species and may rapidly spread into the other adjacent water bodies with the flood water. However, further observations of spotted gar in Monaragala or any other area of the country has not been made so far.

Among the alien invasive ornamental fish with breeding populations, three species (*C. ornatus* (Figure 3-F), *C. batrachus* and *Pangasius* sp.) are active predators of native aquatic fauna. *C. ornatus* is a large voracious carnivore which feeds on slow moving fish. *C. ornatus* with many small bones in the body is not popular as a food fish. The population sizes or the impacts of these piscivores on aquatic biodiversity have not been studied.

The ability of alien species to colonize a new environment is a complex issue and has shown to be influenced by environmental variability, biotic interactions and abiotic disturbances. Freshwater ecosystems are more susceptible for invasion as they are particularly subjected to disturbances and are constantly exposed to degradation throughout the world (Moyle, 1999; Ricciard and MacIsaac, 2000; Michael *et al*., 2004). Sri Lanka constitutes about 153,000 ha of freshwater bodies, which include 70,000 ha of large irrigation reservoirs, 39,000 ha of minor irrigation tanks, 4,000 ha of flood lakes, 8,000 ha of upland reservoirs and 22,000 ha of Mahaweli reservoirs. There is a possibility that the availability of these aquatic habitats, which are interconnected by irrigational channels, would greatly enhance the distribution of aquatic alien invasive organisms throughout the country. Large and sudden changes of flow (floods and droughts) which could increase the habitat availability to invasive biota is a fact that also is applicable to Sri Lankan environmental conditions. Therefore, it is important to introduce laws to restrict new introduction of aquatic species and to take mitigatory measures to restrict further distribution of aquatic invasive alien species with a view to conserve the native species in the country.

The national list of invasive alien fauna published in 2011 (Marambe *et al*., 2011) is incomplete as it does not include two gouramy species that are highly abundant in the aquatic habitats of western, north western, north central and eastern provinces. These two fish species namely, snake skin gouramy (*T. pectoralis*) and three spot gouramy (*T. trichopterus*) have well established breeding populations. While *T. pectoralis* was introduced as a food fish *T. trichopterus* has been accidentally introduced by the ornamental fish trade. *T. trichopterus* still has a commercial demand as an ornamental fish in the country.

Conservation efforts should be directed at preventing these exotics from establishing themselves in new environments. Once invasive species are established, they can be impossible or prohibitively expensive to remove (Myers *et al*., 2000; Pimentel *et al*., 2000; Simberloff, 2003). Presently, aquaculture and ornamental fish farming industries are being promoted by state organizations and NGOs in Si Lanka and risk management measures like quarantine controls are less stringent. While aquaculture and aquarium release are the major pathways for the introduction of alien invasive animals, it has received relatively little attention from both scientists and policy makers. Unless the environmental consequences of escapees of these industries are not addressed the environmental sustainability of aquaculture and aquarium industries are questionable. In order to prevent future invasions by such industries, strategies to reduce propagule supplies such as education of possible ecological and legal consequences of release, or an ability to return unwanted ornamental fish species to commercial aquaria, must be utilized.

Table 1. Intentionally introduced exotic fish species and their present status in Sri Lanka

No	Species and their origin of introduction (FAO, 2014)	Present states
01	*Carassius carassius* - from Europe to Sri Lanka	No feral populations in the country
02	*Catla catla* - from India to Sri Lanka	No feral populations, cultured as a food fish
03	*Cirrhinus mrigala* - from India to Sri Lanka	
04	*Ctenopharyngodon idella* - from China to Sri Lanka	
05	*Cyprinus carpio* - from Europe to Sri Lanka	Head water streams 1500amsl*, cultured as a food fish
06	*Helostoma temminckii* - from Thailand to Sri Lanka	Feral populations in the western province, low market value as a food fish
07	*Hypophthalmichthys molitrix* - from China to Sri Lanka	No feral populations, cultured as a food fish
08	*Hypophthalmichthys nobilis* - from China to Sri Lanka	
09	*Labeo rohita* - from India to Sri Lanka	
10	*Oncorhynchus mykiss* - from United Kingdom to Sri Lanka	One feral population at Horton‘s plain wildlife reserve
11	*Oreochromis mossambicus* - from Eastern Africa to Sri Lanka	Island wide distribution, cultured as a food fish
12	*Oreochromis niloticus* - from unknown to Sri Lanka	

13	*Oreochromis urolepis hornorum* - from Eastern Africa to Sri Lanka used in food fish culture	No feral populations in the country, not
15	*Osphronemus goramy* - from Indonesia to Sri Lanka	Widely distributed in the low country wet zone, ornamental & food fish
15	*Gambussia affinis* - from unknown to Sri Lanka	Widely distributed in the low country wet zone and central province
16	*Puntius gonionotus* - from Indonesia (Java) to Sri Lanka	No feral populations in the country, not used in food fish culture
17	*Salmo trutta* - from Europe to Sri Lanka	
18	*Tilapia rendalli* - from Eastern Africa to Sri Lanka	No feral populations in the country, not used in fish culture
19	*Tilapia zillii* - from Eastern Africa to Sri Lanka	
20	*Trichogaster pectoralis* - from Malaysia to Sri Lanka	Island wide distribution, low market value as a food fish
21	*Puntius javanicus* - from Indonesia to Sri Lanka	No feral populations in the country, not used in food fish culture
22	*Danio rerio* - from (unknown) to Sri Lanka	

* Marambe *et al*. (2011)

Table 2. Aquatic species accidentally introduced by ornamental fish industry

No.	Species	Common name	Present distribution (Province)
01	*Chitala ornatus*	Clown knife fish	Western
02	*Clarias batrachus*	Walking catfish	North western and western
03	*Pterygoplichthys* spp.	Sail fin catfish	Island wide
04	*Poecilia reticulata*	Guppy	Western, southern, central, north western
05	*Trichogaster trichopterus*	Blue gouramy	Western
06	*Xiphophorus maculatus*	Platy	Sabaragamuwa
07	*Lepisosteusoculatus**	Spotted gar	Uwa
08	*Pangasius*	Shark catfish	Western
09	*Pomacea diffusa*	Apple snail	Western, central
10	*Trachemys scripta*	Red eared slider turtle	North western, western

* only one specimen found in 2012

P. pardus **(Lateral view)** ***P. disjunctivus*** **(Lateral view)**

P. pardus **(Ventral view) - A** ***P. disjunctivus*** **(Ventral view) - B**

Figure 2. Identification of sail fin cat fish species (*Pterygoplichthys*, Loricariidae) found in the wild environment in Sri Lanka (Epa and Silva, 2013)

Golden apple snail (*P. diffusa*) - C

Colour variation of *P. diffusa* shells - D

The Spotted Gar (*Lepisosteusoculatus*) - E

Knife fish (*Chitala ornatus*) - F

Figure 3. Golden apple snail, knife fish and spotted gar collected from the wild environment in Sri Lanka

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