

The Survey of the Imported Aquatic Invertebrates via the Live Aquarium Ornamental Trade in Taiwan

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ABSTRACT: In this study, the situation with imported aquatic invertebrates via the live aquarium ornamental trade in Taiwan was investigated from March 2004 to February 2005. The scientific names, native geographic regions, amount, and trade pathways of imported invertebrates were recorded. Among the 108 imported invertebrate species recorded in this survey, 13 are freshwater species, while the others are marine ones, and most of them were from tropical zones. Through the assessments of invasive potential including the imported amount, the similarity of the native geographic regions to Taiwan, and its invasion record, three species from the class Anthozoa (*Cribrinopsis crassa*, *Condylactis passiflora*, and *Alcyonium palmatum*), one from the class Scyphozoa (*Phyllorhiza punctata*), three from the order Decapoda (*Procambarus clarkia*, *Cherax destructor*, and *Neocaridina* sp.), one from the class Bivalvia (*Lima scabra*), and two from the class Gastropoda (*Pomacea bridge* and *Indoplanorbis exustus*) were regarded as having high invasive potentials.

KEY WORDS: Biological invasions, Invertebrates, Aquarium, Taiwan.

INTRODUCTION

Following the development of economic trade and trafficking technology, the rate of biological invasion has increased over the past centuries (Perrings et al., 2005; Ruiz et al., 2000; Vilà and Pujadas, 2001). Invasion by nonindigenous species has caused serious negative impacts on ecology, economics, and human health worldwide. In 2001, the total economic damage associated with nonindigenous species invasions in the US, UK, Australia, South Africa, India, and Brazil were over US\$336 billion (Pimentel et al., 2001). From 1906 to 1991, three invasive aquatic invertebrates in the US caused cumulatively losses of about US\$1207 million (US Congress, 1993). Therefore, due to the great impacts of nonindigenous species, we must

raise concerns both with policy and public attitudes about the challenges posed by biological invasion.

While the biological invasion by charismatic megafauna holds the public's attention, the less-publicized invasion of invertebrates probably results in greater losses of biodiversity (Cowie, 2001). In Hawaiian Islands, 287 nonindigenous marine invertebrate species make up about 7% of the known marine invertebrate fauna, and among the 287 species, 87% have become established (DeFelice et al., 2001). Furthermore, the species abundance of nonindigenous land and freshwater snails is higher than that of native ones (Cowie, 2001). With their high potential for successful invasion, imported invertebrates may cause reductions in biodiversity. On the other hand, most invasion studies have focused on terrestrial ecosystems, while invasions in aquatic ecosystems have been less studied (Carlton, 1992; Carlton and Geller, 1993; Ruiz et al., 2000). In fact, in both freshwater and marine ecosystems, problems of nonindigenous species invasion are very serious (Bailey et al., 2004; DeFelice et al., 2001; Grosholz et al., 2000). Nonindigenous species invasion, together with other man-made environment changes, can induce extinction rates of freshwater fauna five times higher than those of terrestrial fauna (Ricciardi and Rasmusse, 1999).

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According to differences in vectors, two mechanisms of aquatic animal invasion have been categorized: shipping and nonshipping (Ruiz et al., 2000; Shannon et al., 2005). Shipping mechanisms have been extensively studied, and include the invasion of organisms on hulls, in ballast water, or in dry ballast (Carlton, 1992; Carlton and Geller, 1993; David and Perkovic, 2004). Nonshipping mechanisms are further divided into three categories: commercial enterprises, research and educational activities, as well as private and government activities. Each broad category is composed of several subcategories. Commercial enterprises include aquaculture, seafood, bait, and the aquarium ornamentals trade. Research and educational organisms can be imported by public aquariums or universities. Private and government activities can be divided into man-made canals, biocontrol, and coastal restoration (Ruiz et al., 2000; Shannon et al., 2005). Among these, the aquarium ornamentals trade is the most-important pathway of invasion by nonindigenous species worldwide (Cowie, 2001; Hayes et al., 2005; Mack et al., 2000; Semmens et al., 2004; US Congress, 1993; USGG, 2003). For example, among all nonshipping mechanisms, the aquarium ornamentals trade in the state of Massachusetts in the US has been documented to import the highest number of taxa (Shannon et al., 2005). Following the exponential increase in the aquarium ornamentals trade around the world (GMAD, 2005), this pathway will undoubtedly become the most influential mechanism for invasion by nonindigenous species in aquatic ecosystems.

In the past half century, Taiwan quickly progressed from a developing country to a developed country. Following the rise in living standards, pets became a part of many families. Therefore, with the rise in the aquarium ornamentals trade year by year in Taiwan, those imported animals might have escape or have been released into the wild due to misguided cultural habits or incorrect conservation concepts. To prevent the possible invasion by exotic aquarium invertebrates, it is necessary to determine the situation of imported aquarium invertebrates including their names, native geographic regions, amount of trade, and trade pathways.

MATERIALS AND METHODS

Animal surveys

The commercial yellow pages in Taiwan and some internet resources were used to list the aquarium ornamentals industries and pet shops

throughout the region, which consisted of retail stores, vendors in night markets, and wholesalers. From March to May 2004, related stores on this list were preliminarily surveyed. The scientific name and common name of each imported invertebrate organism were recorded, and its numbers were counted or estimated. For unidentified organisms, pictures were taken, and their taxonomic characters were recorded for future identification.

After the preliminary survey, stores which did not sell imported invertebrate organisms, and relatively small retail stores which displayed only the common species easily found in large stores were excluded from the following surveys. The surveys were continued for the next three seasons (June to August, September to November, and December 2004 to February 2005).

Data on native species in Taiwan were retrieved from the TaiBNET database (<http://taibnet.sinica.edu.tw/home.htm>). The ratios of native and imported species numbers at the family level for freshwater species and at the class or order level for marine species were calculated.

Invasive potential

Because the native geographic region of an imported aquarium ornamental invertebrate is one of the important indicators for evaluating its invasive potential, information on the native geographic regions of those animals was gathered by searching the literature and relevant networks. For freshwater species, the geographic regions were divided into Africa, Southeast Asia, East Asia, Central Asia, South Asia and the Pacific Islands, Europe, North America, South America, and Oceania. For marine species, the geographic regions were distinguished as the Pacific, Atlantic, Mediterranean, Indo-Pacific, Indo-Pacific-Atlantic, Indo-Pacific-Mediterranean, and circum-global.

In order to establish an invasive potential assessment of imported aquarium invertebrate species, four indexes, including the number, frequency, native geographic region, and known invasion situation around the world, were used. The number indicates the amount of trade in that organism. The frequency means the ratio of stores selling a particular species among all surveyed stores. The native geographic regions and known invasion situations were obtained from literature sources. Species from geographic regions with similar latitudes to Taiwan were regarded as having higher invasive potentials.

RESULTS

Composition of imported species

According to this survey, the aquarium ornamental industry commonly imports 108 invertebrates including marine and freshwater species into Taiwan. Thirteen freshwater and 96 marine species were identified in the 280 surveyed stores (Tables 1 and 2). Among the freshwater species, 62% belong to the order Decapoda, and the others belong to the class Gastropoda. The majority of imported freshwater species included freshwater shrimp, crayfish, and freshwater snails. Among the imported marine species, 73% belong to the class Anthozoa, 11% to the order Decapoda (class Crustacea), and the others to the classes Bivalvia, Holothuroidea, and Asteroidea, as well as the orders Nudibranchia (class Gastropoda) and Canalipalpata (class Polychaeta). The majority of marine species included corals, sea anemones, shrimp, crabs, clams, tube worms, starfish, and sea cucumbers.

For most of the imported freshwater families, the species numbers were lower than those of the native ones, and a similar situation occurred for most imported marine orders or classes (Table 3). In addition, in freshwater organisms, the three families of the Cambridae, Parastacidae, and Ampullariidae had not previously been recorded in Taiwan. However, for marine organisms, because of a lack of biodiversity data in Taiwan, we were not able to compare variations between native and imported species in the class Scyphozoa or the order Canalipalpata.

From March 2004 to February 2005, the composition of the imported freshwater and marine species did not exhibit remarkable differences, except that the number of species of the class Anthozoa decreased in fall and winter (Table 4). This decrease was the result of the disappearance of rare species, but common species were still present in the surveyed stores. This steady composition may have been due to the importation of species from tropical areas, where specimens can be collected during the entire year with few seasonal influences.

Invasive potential

Most of the native geographic regions of imported freshwater invertebrate species are Asia

and the New World (Table 5). The most-important freshwater snails were from South Asia-Pacific Islands (75%), and the native geographic regions of the freshwater shrimp and crayfish were Southeast Asia, South Asia-Pacific Islands, North America, and Oceania. Most of the imported marine invertebrate species were from the Indo-Pacific and Pacific regions. Only a few were from the Atlantic and Mediterranean regions (Table 6). Most of the freshwater and marine species were from tropical zones.

Under the invasive potential assessment, three species from the class Anthozoa (*Cribrinopsis crassa*, *Condylactis passiflora*, and *Alcyonium palmatum*), one from the class Scyphozoa (*Phyllorhiza punctata*), three from the order Decapoda (*Procambarus clarkia*, *Cherax destructor*, and *Neocaridina* sp.), one from the class Bivalvia (*Lima scabra*), and two from the class Gastropoda (*Pomacea bridge* and *Indoplanorbis exustus*) were regarded as having high invasive potentials according to the four indexes described above. Although the frequency and the number of *C. passiflora* or *L. scabra* were low and no invasion record yet, the environmental conditions of their origin region, Caribbean or West Atlantic, are similar to Taiwan. Therefore, it might have high potential to invade Taiwan. The frequency and the number of *P. punctata* were also low, but it has successful invasion record already (Table 7). Five of them have successful invasion record, and *P. clarkia* is the only species that had already been documented as having invaded Taiwan (Chen et al., 2003). In this survey, no poisonous or harmful species to humans were found.

DISCUSSION

The risk of successful invasion is likely to increase with taxonomic diversity and the numbers of individuals (Carton et al., 1993; Levine and D'Antonio, 2003; Shannon et al., 2005; Smith et al., 1999). Our results showed that the aquarium trade in Taiwan imports invertebrate species with a complex taxonomic structure, including total species numbers

Table 1. Taxonomic composition of the imported freshwater ornamental invertebrates recorded from March 2004 to February 2005 in Taiwan.

Phylum	Class	Order	Family	Number of genera	Number of species
Arthropoda	Crustacea	Decapoda	Cambridae	1	2
			Atyidae	3	3
			Coenobitidae	1	1
			Parastacidae	1	2
			Ampullariidae	1	1
Mollusca	Gastropoda	Architaenioglossa	3	3	
		Archaeogastropad	3	3	
		Basommatohora	1	1	

Table 2. Taxonomic composition of the imported marine ornamental invertebrate species recorded from March 2004 to February 2005 in Taiwan.

Phylum	Class	Order	Family	Number of genera	Number of species				
Cnidaria	Anthozoa	Alcyonacea	Alcyoniidae	4	7				
			Nephtheidae	2	2				
			Sphaerellaceae	1	1				
			Xeniidae	1	1				
			Gorgonacea	Subergorgiidae	1	2			
				Pennatulaceae	1	1			
				Stolonifera	1	2			
			Cornulariidae	Cornulariidae	1	1			
				Tubiporidae	1	1			
				Actiniaria	Actiniidae	5	6		
			Actinostolodae		1	1			
			Andresiidae		1	1			
			Stichodactylidae		3	4			
		Ceriantheria	Arachnanthidae		1	1			
			Cerianthidae	1	2				
		Corallimorpharia	Actinodiscidae	2	2				
			Discosomatidae	2	3				
		Scleractinia	Actinoptera	Acroporidae	1	1			
				Dendrophyllidae	2	2			
				Euphyllidae	2	7			
				Faviidae	2	3			
				Fungiidae	2	2			
				Mussidae	3	6			
				Pectiniidae	1	1			
				Poritidae	3	5			
				Trachyphyllidae	1	1			
				Zoanthidea	Parazoanthidae	1	1		
					Zoanthidae	2	3		
				Arthropoda	Crustacea	Decapoda	Mastigiidae	1	1
							Enoplometopidae	1	1
		Hippolytidae	2				3		
		Hymenoceridae	1				1		
		Majidae	1				1		
Pontoniidae	1	1							
Rhynchocinetidae	1	1							
Stenopodidae	1	2							
Mollusca	Bivalvia	Limoida	Limidae				1	1	
			Ostreoida				Spondylidae	1	1
			Veneroida				Tridacnidae	1	3
Gastropoda	Nudibranchia	Chromodorididae	1				1		
		Hexabranthidae	1				1		
Echinodermata	Holothuroidea	Cryptozoma	Ophiasteridae	1	1				
			Oreasteridae	1	1				
			Stichopodidae	1	1				
			Dendrochirotida	1	1				
Annelidae	Polychaeta	Canalipalpata	Sabellidae	1	1				
			Serpulidae	3	3				

and taxonomic diversity. Therefore, this high taxonomic diversity represents serious invasive potential for the aquatic ecosystems of Taiwan.

Many authors have emphasized that greater concern with the biological and ecological characters of the invasive species is necessary to assess the potential for invasion (Byers and Goldwasser, 2001; Fausch et al., 2001). Among marine invertebrates, the classes Bivalvia and Crustacea have been the most-successful invaders in North America and the Hawaiian Islands (DeFelice et al., 2001; Ruiz, 2000). The high invasive succession capabilities of the two taxa suggest that

we should more-seriously consider the threats they pose. According to the results of this survey, the highest percentage of imported species belonged to the phylum Cnidaria, which had a high ratio of imported species number to native species number in Taiwan. But this situation might not reflect the invasive success of marine ecosystems of this island. Their failure to successfully establish themselves may be related to the low survival rate of those species in most aquaria.

In many regions, the invasion of crayfish has induced some disease transmission and has had tremendous impacts on both ecosystems and

Table 3. Comparison of species numbers of native and the imported aquarium invertebrates recorded from March 2004 to February 2005 in Taiwan.

Taxon	No. of native species (NN)	No. of imported species (NI)	NI/NN
Freshwater			
Cambridae	0	2	∞
Atyidae	13	3	23%
Coenobitidae	4	1	25%
Parastacidae	0	2	∞
Neritidae	45	3	7%
Ampullariidae	0	1	∞
Planorbidae	6	1	17%
Marine			
Anthozoa	328	70	21%
Scyphozoa	ND	1	ND*
Decapoda	1200	10	8%
Bivalvia	784	5	1%
Holothuroidea	44	2	5%
Asteroidea	30	2	7%
Canalipalpata	ND	4	ND*
Nudibranchia	12	2	33%

Table 4. Numbers of species of the imported aquarium ornamental invertebrates in different seasons from March 2004 to February 2005 in Taiwan.

Taxon	March~May	June~August	September~November	December~February
Anthozoa	63	61	52	44
Scyphozoa	0	1	0	0
Decapoda	17	16	11	12
Bivalvia	5	5	5	2
Gastropoda	4	6	6	5
Holothuroidea	2	2	2	2
Asteroidea	2	2	2	2
Canalipalpata	4	4	4	4

Table 5. Percentages of native geographic regions of the imported freshwater aquarium ornamental invertebrates.

Class	Africa	Southeast Asia	East Asia	Central Asia	South Asia/Pacific islands	Europe	North America	South America	Oceania
Gastropoda	0	0	0	0	75	0	0	25	0
Decapoda	0	22	0	0	22	0	33	0	22

* This survey was done from March 2004 to February 2005 in Taiwan.

Table 6. Percentages of native geographic regions of the imported marine aquarium ornamental invertebrates.

Taxon	Pacific	Atlantic	Mediterranean	Global	Indo-Pacific	Indo-Pacific-Atlantic	Indo-Pacific-Mediterranean
Nudibranchia	33	0	0	0	67	0	0
Decapoda	0	10	0	0	70	20	0
Scyphozoa	100	0	0	0	0	0	0
Bivalvia	20	20	0	0	60	0	0
Anthozoa	9	9	6	1	68	6	1
Holothuroidea	50	0	0	0	50	0	0
Asteroidea	0	0	0	0	100	0	0
Canalipalpata	25	0	0	25	25	25	0

* This survey was done from March 2004 to February 2005 in Taiwan.

agriculture (Correia, 2002; Holdich, 2002; Laurent, 1997; Skurdal, 1995). Two crayfish species which have invaded areas worldwide, *Procambarus clarkia* and *Cherax destructor*, have been imported into Taiwan. In earlier years, *P. clarkia* was imported for aquaculture or the aquarium trade, but this species escaped or was released into freshwater ecosystems and has successfully established local populations (Gao and Hong, 2001). Unfortunately, their impacts on ecosystems and agriculture have yet to be estimated in Taiwan. Recently, a new

crayfish species, *C. destructor*, was imported from the Southern Hemisphere. In a comparison of the native geographic region and invaded regions, this species has been reported as high ecological plasticity (Holdich, 2002). Therefore, it is quite necessary to further manage this species, such as decreasing imports and limiting marketing of this species.

Invasion by freshwater snails can cause other serious problems. Over the past few decades, at least three snail species were discarded into US waters by

Table 7. The display frequency and amount of the imported aquarium ornamental invertebrates with high invasive potential.

Taxon	Scientific name	Number	Frequency (stores selling/ stores surveyed)	Region of origin	Invasive situation
Anthozoa	<i>Cribrinopsis crassa</i>	> 400	32/278	Mediterranea	
	<i>Condylactis passiflora</i>	28	3/278	Caribbean	
	<i>Alcyonium palmatum</i>	#	9/278	Mediterranea	
Scyphozoa	<i>Phyllorhiza punctata</i>	5	1/278	Australia	Hawaii and the Caribbean ¹
Decapoda	<i>Procambarus clarkii</i>	> 1000	28/278	North America	Taiwan ²
	<i>Cherax destructor</i>	> 700	25/278	Australia	Europe ³
	<i>Neocaridina sp.</i>	> 400	17/278	Southeast Asia	
Bivalvia	<i>Lima scabra</i>	> 100	10/278	West Atlantic	
Gastropoda	<i>Pomacea bridge</i>	> 300	7/278	South American	Southeast Asia, Hawaii ⁴
	<i>Indoplanorbis exustus</i>	#	200/278	India	N. America, Great Lakes ⁵

* This survey was done from March 2004 to February 2005 in Taiwan

The number was too great to estimate in the store.

1. DeFelice et al., 2001.

2. Chen et al., 2003.

3. Holdich, 2002.

4. <http://www.applesnail.net/>

5. <http://www.ijc.org/rel/montreal/pdf/macisaac.pdf>

aquarium dealers or customers (US Congress, 1993), and the invasion by freshwater snails caused the loss of native freshwater snail diversity on Pacific Islands (Cowie, 2001). The invasion of freshwater snails on Pacific Islands was dominated by Asia/Australasia and New World species, and one of the important pathways of snail introduction into the Pacific Islands was the aquarium trade (Cowie, 2001). Similarly, all imported freshwater snails in Taiwan are from South Asia, the Pacific Islands, and South America. Because two of the five imported ornamentals freshwater snails in Taiwan have already invaded the Pacific Islands (Cowie, 2001), the nonindigenous freshwater snails imported into Taiwan may also have high invasive potentials. Actually, in the past two decades, one land snail, *Achatina fulica*, and one freshwater snail, *Pomacea canaliculata*, have successfully become established in Taiwan and have caused serious negative impacts on agriculture. According to this situation, it is inferred that the ecological condition of Taiwan is very fragile with respect to gastropod invasion.

Regardless of whether one is considering freshwater or marine species, tropical regions are the major source of aquarium invertebrate ornamental species in Taiwan. This situation is similar to that in the US (Shannon et al., 2005). DeFelice et al. (2001) also showed that non-indigenous invertebrate species in the Hawaiian Islands primarily originated in the Indo-Pacific/Philippine Islands and tropical Western Atlantic/Caribbean regions. Those facts point out that regional aspects should be taken into consideration when assessing invasion risks (Shannon et al., 2005). The complicated geographic situation in Taiwan offers various aquatic habitats for imported invertebrates to colonize. Such a situation is particularly relevant in southern Taiwan. Because

the environmental factors, latitudes, and habitats of southern Taiwan are similar to those of the Hawaiian Islands, serious environmental problems with invasive species in the Hawaiian Islands may likewise occur in southern Taiwan if we do not pay attention in the future.

The number of imported species is a classic index of invasion; however, this index may result in misplaced concerns for taxonomic groups with higher species numbers but with ignorance of differences in the post-importation invasion mechanisms. For the aquarium ornamentals trade, the important assessment indexes of post-importation invasion mechanisms include distance between the nearest water body and the aquarium ornamental store, as well as the handling of discharged tank water (Shannon et al., 2005). In Taiwan, there are no rules regulating how aquarium ornamental stores discharge tank or agriculture water. Therefore, the distance between the nearest water body and the stores is the most-important index. Aquarium ornamental stores in Taiwan are usually in the major cities far away from the sea. This means that untreated tank water is always discharged directly into freshwater channels or rivers where most marine species might not survive.

However, the situation is reversed for freshwater species. Although imported freshwater species had lower taxonomic diversity, they may have higher invasive potential in Taiwan. However, marine species might also be released directly into the sea. Hence, completely ignoring the invasive potential of marine species is dangerous. On the other hand, end-users need to be educated because dealers have no subsequent control over owners' actions after organisms are sold (Mack et al., 2000). In Taiwan, a special situation, the deliberate release of animals, should be highlighted. This religious activity,

widely accepted by some Buddhist branches in an effort to accrue good karma, has recently been noted and challenged. No exact numbers of released animals has been determined, but thousands of animals of both native and exotic species are purposely released into the wild in Taiwan every year. Such non-appropriate concepts or dogma should be changed by education or restricted by legislation.

In order to prevent biological invasion, the authorities concerned should establish multi-aspect invasion risk assessments and continue annual surveys of imported aquarium ornamental invertebrates as a long-term activity. For the diverse factors influencing biological invasion, multi-aspect invasion risk assessment, including ecological and biological features of imported species, environmental factors, and post-importation invasion mechanisms, should be established (Hendrix and Bohlen, 2002; Ruiz et al., 2000; Semmens et al., 2004; Shannon et al., 2005). Recent research showed that nonindigenous species in the Hawaiian Islands are increasing at a rate of one species per year (Cowie, 2001). This indicates that surveys of imported aquarium ornamentals invertebrates should be continued as a long-term activity. Annual updates and reassessment of the record are necessary.

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臺灣水族寵物貿易引進水生無脊椎動物種類之調查現況

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摘 要

本研究於 2004 年 3 月至 2005 年 2 月間，調查臺灣本島經由水族寵物貿易所引進的水生無脊椎動物，並紀錄這些物種的學名、原產地、數量與引入管道。研究中所記錄的 108 種引進種多來自熱帶地區，其中僅 13 種為淡水物種，其餘的皆為海水物種。在考量各物種的引進量、原產地環境特性與臺灣的相似性及是否有入侵記錄後，初步入侵風險的評估結果顯示，軟體動物腹足綱的 *Pomacea bridge* 和 *Indoplanorbis exustus* 及雙殼綱的 *Lima scabra*、甲殼動物的 *Procambarus clarkia*、*Cherax destructor* 和 *Neocaridina* sp.、刺絲胞動物珊瑚蟲綱的 *Cribrinopsis crassa*、*Condylactis passiflora* 和 *Alcyonium palmatum* 及鉢水母綱的 *Phyllorhiza punctata* 具有較高的入侵風險。

關鍵詞：生物入侵、無脊椎動物、水族館、臺灣。

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