Invasive Species in Freshwater Ecosystems – Threats to Ecosystem Services

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CHAPTER

9

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1 INTRODUCTION

Geographical barriers to species distribution are being increasingly broken down by human activities (Su et al., 2016) through intentional or unintentional introductions (Minchin et al., 2013) as species were moved out of their area to relatively new region for recreation, trade, food and other economic interests across world. In recent times, the redistribution of species is one type of environmental change associated with global climate change. Consequently the combined effect may blur the boundaries between native and non-native species providing enough chances for the introduction of alien species into a new area. Moreover, a native species that may not have caused problems in a native region could become invasive in another region. Conversely, with the change of climatic parameters an invasive species may become less of a problem in the same region.

It is essential to clearly define the native and non-native species to understand the invasion of new species into a new area. Non-native species, like native species can be beneficial, harmful or negligible in their effect. When a non-native species causes harm of some sort, it is viewed as invasive. In common parlance, invasive species refers to non-native species that are producing negative consequences in the environment or producing effects that humans don't like and deem harmful. These ill effects are seen in three-manifestation viz., economic harm, threats to human health and impacts on ecological services. Some species may cause more than one type of harm, and/or the type of harm might change over time.

A large population of an invasive species can start from a very small number of individuals, and those individuals can be difficult to see, so they may easily go unnoticed. The tiny

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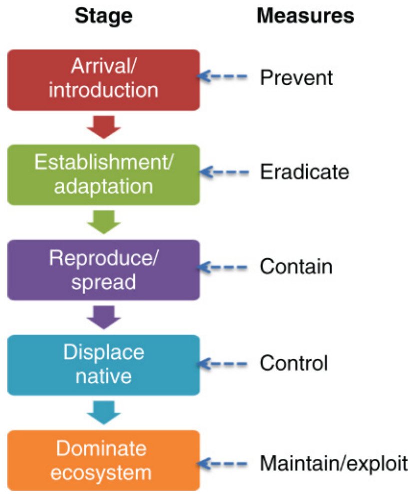

FIGURE 9.1 **Stages of biological invasion.**

young of invasive shellfish, an egg or juvenile, a fragment of an aquatic weed can be enough to establish a population under favourable environmental conditions that could ultimately cost millions of dollars to address. The longer infestations are allowed to progress, the more extensive the damage and control costs and less efficient the control efforts. Non-native species invade through a five-stage invasion process (Fig. 9.1). Eradication becomes increasingly difficult, and eventually impossible, as the invasion advances. However, if populations are detected early enough, eradication may still be possible. Though prevention is the best strategy for managing invasive species, 'early detection and rapid response' efforts are the most effective and cost-efficient responses to invasive species that become introduced and get established aided by climate change/favourable conditions.

Alternatively a species causing just ecological harm at the outset may begin to produce economic harm as time proceeds due to climate imposed ecological changes. With the impending climate change affecting the tropical islands more than the continental countries the impact of invasive species will apparently have a deleterious effect on native freshwaters fishes and other aquatic lives. The tropical island of Andaman and Nicobar Islands, India has a long history of alien fish introduction for aquaculture (Rajan and Sreeraj, 2014). Till date the impact of invasive species on native ecosystem in the context of climate change has not been adequately documented vis-a-vis other tropical islands. Therefore, in this chapter, the impact of non-native species on aquatic ecosystem in reference to habitat modification by means of climate change is critically reviewed.

2 IMPACT OF INVASIVE SPECIES ON NATIVE ECOSYSTEM

Invasive alien species (IAS) have resulted in major impacts on biodiversity at a global scale, where at least 39% of the species extinctions during the past 400 years are due to IAS (www.indiaenvironmentportal.org.in/node/38152). Introduced non-native species particularly fishes can cause considerable impacts on freshwater ecosystems (Copp et al., 2017) and are problematic for managers because they are so unpredictable (Strayer, 2010). There is a tendency for introduced aquatic organisms to adopt a niche that differs completely from that occupied in native range (Cagauan, 2007). Sometimes positive effects of non-native species have also been observed.

2.1 Negative Effect

Deliberate or accidental introduction of fish species is considered as most insidious threat to fish conservation around the world Movement of aquatic fauna particularly fishes is of no exception over the decades, several countries have already established invasive fish species in their native waters, which may compete with native fishes for food, space and survival. In general, introduction and spread of invasive species under changing climatic conditions will produce unfavorable effects on three different aspects viz., environmental, wildlife and public health and economic impacts (Table 9.1). It is not likely that a single species will bring all the changes in any aquatic system rather it can be well adapt to the new environment. But with the change in climate and the altered situation may convert these alien species as invasive, which tend to dominate the ecosystem in due course of time. Like habitat destruction, invasions of non-native fishes could also interrupt resource flows and have far reaching effect in inter-connected ecosystems (Baxter et al., 2004).

Among Asian countries India possess the maximum number of endemic freshwater finfish species (27.8%) followed by China, Indonesia and Myanmar (Lakra et al., 2010). The freshwater aquatic biodiversity is depleting alarmingly due to the introduction of exotic species (Kumar, 2000), predation, parasitism and other anthropogenic activities. Exotic fishes are seen as a threat to the introduced ecosystem, as it causes significant changes in the composition of ecosystem, which make a native fauna to compete with exotics for food and space. Species diversification in aquaculture has gained importance as a result, several species, which are known for higher growth rate and increased production, were introduced all over the world. Aquaculture is a major source of invasive aquatic species despite the fact that cultured organisms often have low genetic diversity and tend to be maladapted to survive in wild (Consuegra et al., 2011). As a result of this, alien species are recognised as one of the most significant threat to the aquatic biodiversity (Raman et al., 2013). Such problems are not happening in a region or closed system but has global in consequences. Introduction of alien fish

TABLE 9.1 Impacts of Aquatic Invasive Species in the Native Ecosystem

Environmental effects	Wildlife and public health	Economic impacts
Predation	Epidemics	Commercial fishing
Parasitism	Parasites	Shipping
Competition	Viral/bacterial	Recreational activity
Introduce pathogens	Health hazard	Water supply
Cross breeding	Ecosystem services	Industrial water use
Habitat alterations	Ecological value	Mass extinction

species has also resulted in major global change, harming native species and communities throughout the world (Rahim et al., 2013). In many aquatic systems of islands, the invasive species are so strong that the native fauna has been displaced or in verge of threat due to introduction of alien fish species.

2.2 Dichotomy of Alien Species

Sometimes introductions into the fishponds for aquaculture purposes will accidentally expose the exotic fishes to native aquatic systems, which will proliferate and establish their presence, which in turn will be a competitor for food and space with native fishes of ecosystem. Of the eight worst species listed by Cambray (2003), four of them are common in India. Sultana and Hashim (2015) reports that eight common fishes including *Carassius auratus*, *Cyprinus carpio*, *Oncorhynchus mykiss*, *Oreochromis mossambicus*, *Poecilia reticulata*, *Salmo salar, Salmo trutta* and *Salvelinus fontinalis* are the invasive alien fishes in all continents except Antarctica. In contrast, in several instances exotic fishes have also shown positive impact on the aquaculture production and effective management. Though detrimental, alien fishes are seen as important food fish contributing as source for livelihood of fishers in India except *Gambusia affinis*, which is used familiarly for mosquito control programmes. Island ecosystem on other hand being cut off from main land mostly remains biodiversity hot spot with high level of endemism. The presence of surrounding marine environment and physical distance from mainland limit the number of taxa of organisms that can naturally reach and colonise islands (Reaser et al., 2007).

In India, two main island regions, which are located in the tropical water, are Andaman and Nicobar Islands and Lakshadweep. Lakshadweep Islands lying in Arabian Sea are completely marine based flat low lying islands, whereas Andaman and Nicobar Islands is predominantly marine based, however, has endemic freshwater fishes and high demand towards freshwater fishes prompting fishers to import freshwater fishes from main India for culture and consumption. Several freshwater fishes introduced in the islands have become established populations comprising mainly of tilapia, catfishes, murrels and carps. Freshwater fishes of Lakshadweep Islands were also studied by Sirajudheen and Khan (2014a,b) and found that freshwater fishes were introduced in to Lakshadweep Islands more recently post 2008 and 16 species of freshwater fishes were reported from Lakshadweep Islands. Surprisingly the islands being at a great distance from mainland has established populations of the exotic fishes brought mainly for reasons like aquaculture, recreation, ornamental culture and intentional/unintentional entry through import of seeds. Islands ecosystems are naturally fragile and are vulnerable to any external influences either in form of invasive species or natural disasters and hence it is utmost importance to understand the concepts of endemism, exotic fishes and impacts on native species in island ecosystems.

2.3 Zoogeographic Pollution

Camray (2003) refers the fish introductions as zoogeographic pollution when the organisms are moved out of their known home range and introduced into new areas by humans. The introduction pathway analysis of Sultana and Hashim (2015) shows that aquaculture contributes major percentage of reasons for introduction in South America, North America, Europe, Australia and Africa. Many species introduced by humans for social and economic benefits have invaded new ranges by escaping from captivity (Liu and Li, 2009). Alien fishes introduced for aquaculture purposes have great potential to move out of their enclosures particularly species like catfishes. Even in Brazil, Britton and Orsi (2012) reports that non-native such as *C. carpio*, *O. niloticus* in Brazil are highly potential invasive and deleterious species to native fish diversity as per ecological risk assessment studies. In Aceh, Indonesia, 10 introduced species are reported of which *O. mossambicus* is most widely distributed (Muchlisin, 2012). In case of Malaysia, there is no restriction on the spread of alien fishes in natural habitat, however, the negative impact of alien fishes on native fauna is very early to conclude (Rahim et al., 2013).

Another form of important invasion is through ornamental fish industry as freshwater ornamental sector is a flourishing business across world. The Northern snakehead fish *Channa argus*, a native of China was reported in MA, USA and experts believed that snakehead entered the waters through aquarium and live fish food trade (Robinson, 2007). *Channa* sp. generally having burrowing ability in moist soil makes it difficult to eradicate (Cagauan, 2007) should be a real concern.

3 ECONOMIC SIGNIFICANCE OF NON-NATIVE FISHES

Asia is one of the most leading aquaculture producing regions with several introductions of fishes, which is source of livelihood for millions of people. Several exotic fishes were being brought into India for sport fishing and culture activities. Exotic fishes are being introduced into Asia for variety of reasons. Sultana and Hashim (2015) reports that the major introduction pathways in Asia are mainly contributed by aquaculture (21%), aquarium trade (19%) and live food trade (17%). In Asia, introductions of *Gambusia* sp., *Poecilia* sp., *Channa* sp., *C. carpio*, *Ictalurus punctatus* and few more for reasons such as mosquito control, ornamental purposes and food consumption (Cagauan, 2007). During the last several decades, over 300 species of exotic fishes have been brought into India for experimental aquaculture, sport fishing, mosquito control and aquarium keeping (Kumar, 2000). Some of the important exotic introductions in India include *Carassius Carassius*, *C. carpio, Ctenopharyngodon idella, Hypophthalmichthys molitrix* and tilapia. De Silva et al. (2006) reports that tilapias, catfish, Chinese and Indian major carps (IMC) are significant in Inland aquaculture sector of Asia. They too record that introduction of tilapia is seen too most beneficial as they have great consumer preference. In Indonesia, Inland culture is dominated by alien production of common carp, which fetchs high income for the native people (De Silva et al., 2006). In Philippines, exotic aquatic organisms are primarily used for ornamental species (76%), followed by food (21%) and biological control (2%) (Cagauan, 2007).

Aquarium trade is an important and rapidly growing vector for introduced species in the United States (Chang et al., 2009). Majority of exotic fishes present in Florida waters came through ornamental aquarium fish industry (Courtenay et al., 1974). In Andaman and Nicobar Islands, many of the introduced alien fish serve as a good source of protein and fetches very good market price. The species like *O. mossambicus*, *Heteropneustes fossilis*, *Clarias magur, Ch. striata* and *Anabas testudineus* fetches a very high price in the look market and considered as a great delicacy among the native settlers. Tilapia due to its proliferative breeding behavior has established its population strongly in native waters of India. Silver carp introductions caused significant effect to native populations of *Catla catla* in India due to the fact that both are surface feeders and Silver carp competing for food and space with *Ca. catla*. The deleterious effect of climbing perch (*A. testudineus*) observed by Paliwal and Bhandarkar (2014) as it is known to kill reptile, waterfowl and fishes preying on it. The effects of introduction of *Cl. gariepinus* in India was discussed by Krishnakumar et al. (2011) in natural water bodies of Kerala particularly Vembanad Lake. *Cl. gariepinus* introduction in Brazil was also found to pose serious potential for impact on the native fish fauna as these fishes were introduced as escapees from ponds built for recreational angling (Vitule et al., 2006). Illegal introductions of *Aristichthys nobilis*, *Cl. gariepinus*, *Pangasianodon hypothalamus*, *O. niloticus*, *Pygocentrus natterei* and *Piaractus brachypomus* was reported by Singh and Lakra (2011a,b). Landward movements of alien fishes throughout India make it difficult to control their expansion as fishes are brought illegally from nearby countries and within country. Possibilities of introduction of new diseases also cannot be ruled out in such conditions. Though strict enforcement of law can be strengthened further, the extent of damage has already incurred in the freshwater ecosystems of India and further aggravation of the deleterious effects could only be controlled if strict guidelines and framework of alien fish introduction are formulated as region specific.

4 CLIMATE CHANGE AND NON-NATIVE FISHES

Climate change is emerging as one of the main challenges that humankind will have to face for years to come (Dam Roy et al., 2017a). Climate change and invasive species are two of the most pervasive aspects of global climate change (Rahel and Olden, 2008). Climate change and invasive species are two complex phenomenons that offer threat to biodiversity and livelihood, however the impact of climate change events and their mitigation strategies has gained more importance over invasive species around world. Climate change and biological invasions are key processes affecting global biodiversity yet their effects have usually considered separately (Walther et al., 2009). The link between climate change and biological invasions is key process in understanding the expansion or decline of an introduced species in a particular geographic region. The observed and projected climate change under different Special Report on Emissions Scenarios (SRES) shows that climate change affects pathways of species introduction, establishment of non-native species, moderate the effect of deliberate change (Fig. 9.2). Biological invasions coupled with climate change drives changes in marine biodiversity (Holopainen et al., 2016) and probably in freshwater ecosystem too.

The success of an introduced alien species in to a new system vastly depends on climate change events, which may influence their food, reproduction, survival and expansion. Climate change can facilitate IAS through change in species hierarchies, invasive pathways through climate-induced stress (Masters and Norgrove, 2010) and also their possible migrations. Climate suitability was commonly used as the most important factor for predicting the potential distribution of invasive species (Liu and Li, 2009), which shows how important influence could climate change events have on invasive species. Though introduction and establishment of invasive species are of global concern (Chandra and Gerhardt, 2008) their impact on native ecosystem and the influence of climate change pattern prevailing and their effect on introduced species is important. Climate change enhances the habitat disturbance,

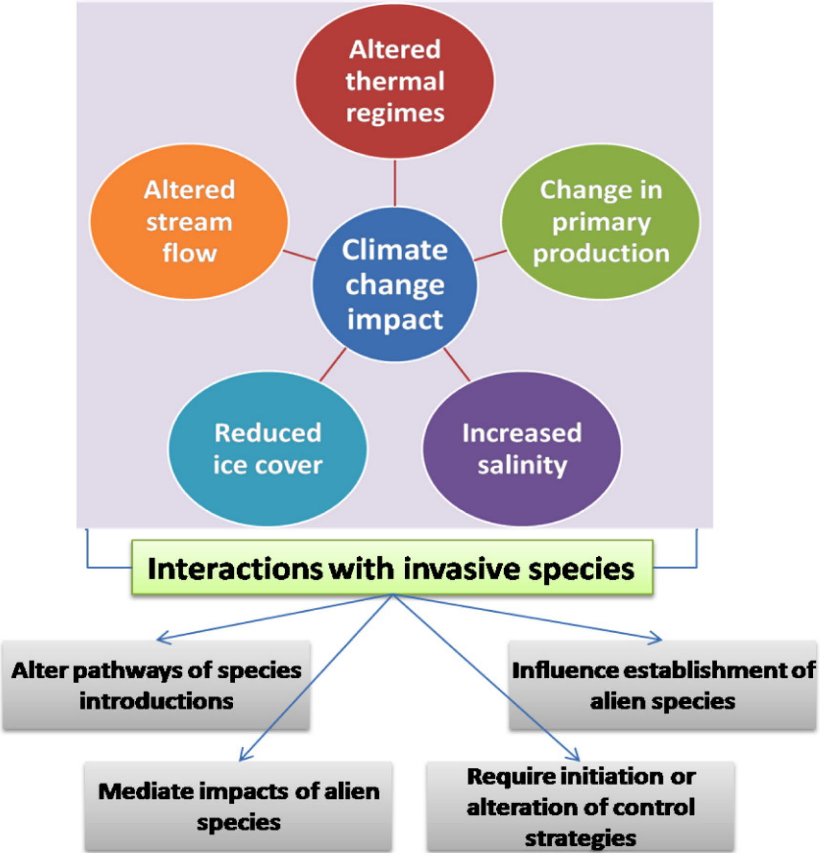

FIGURE 9.2 **Impacts of climate change on aquatic systems.**

which facilitates establishment of invasive species (Chown et al., 2015). Fish introduction and climate change could be an interesting link as climate change events such as rainfall pattern, storms, tsunamis, cyclones and drought are all having an interlink with the aquatic biodiversity. Climate change will likely affect on fish physiology, water chemistry, quality and flow regimes, which will have changes on fish population (Ficke, 2005). Alterations in climate and extreme weather events are likely to result in future changes of marine and brackish water alien species (Minchin et al., 2013) in British coast.

The influence of climate change events is more pronounced in islands due to their small area, landscape and coastal populations. Wetlands play significant role in livelihood of island population, as fisheries and tourism being backbone of island economy will be depending on wetlands. Wetlands have significant value to tropical islands owing to their significance in terms of biodiversity, coastal protection and economic values (Dam Roy et al., 2017b). In Andaman and Nicobar Islands the freshwater fisheries are a major source of livelihood for thousands of fishing communities. Aquaculture sector is facing major pressure due to increasing population and high demand owing to which freshwater fishes were introduced for species diversification and increased production. Interestingly over the decade, the island faced severe events such as increased sea surface temperature, cyclones, storms, tsunami, earthquakes, rainfall pattern variations and drought which all had an impact on aquatic ecosystems of islands. Sea surface temperature and storms has created damages to coral reef ecosystems (Krishnan et al., 2011, 2012), mangrove stands has been affected due to tsunami (Dam Roy and Krishnan, 2005) and sea grass medows due to cyclones (Sachithanandam et al., 2014). Reaser et al. (2007) states that the intrinsic resilience of island ecosystems is determined by ecological factors and extrinsic resilience dictated by natural disasters and socio economic forces. Many of the impacts of climate change in Andaman and Nicobar Islands are studied on marine ecosystems wherein the freshwater bodies and their response to climate change events are rare. Given that human activity and temperatures are expected to increase in future aquatic fauna of the islands will show responses either physical or biological, which needs to be studied to establish relation between climate change and alien fish fauna in Inland ecosystems.

5 SOME CASE EXAMPLES FROM TROPICAL ISLANDS

As discussed earlier in this chapter, invasive species are now considered to represent the greatest threat to island biodiversity and habitat loss. There are two main factors worth mentioning here. Firstly, many of the tropical islands are particularly valuable centres of biodiversity. Their physical isolation from the continental mainland, and the dynamics of natural colonisation and local evolutionary adaptation that result, often leads to the development of unique biotas. Endemism is a common feature of the flora and fauna of islands. Secondly, islands appear to be particularly vulnerable to the impact of invasive species. A number of reasons have been cited for this such as, low density of indigenous species providing for greater vacant niche space and less competition than would be found on the mainland, the small size of island populations rendering them prone to extinction, evolutionary effects of isolation on island species leading, for example, to loss of defensive behaviours and consequent vulnerability to introduced predators. Other factors that have been cited as increasing the impact of invasive species on islands include release of introduced species from natural enemies resulting in absence of predators and competitors that regulate their numbers in continental populations, and patterns of human exploitation of islands. In the following sections, some of the unique invasions and its consequences with reference to Andaman and Nicobar Islands, Lakshadweep, Sri Lanka, Pacific Ocean islands and Caribbean regions are discussed.

5.1 Andaman and Nicobar Islands

Andaman and Nicobar Islands is bestowed with unique freshwater biodiversity with high level of endemism. Very few studies were conducted on freshwater ecosystems on par with marine and still the actual diversity of freshwater fishes in Andaman and Nicobar Islands is poorly understood. Though the islands possess coastline of 1912 km and about 1/4th of exclusive economic zone with marine fisheries being emphasised in view of livelihood, the freshwater diversity too possesses its own significance. Their contribution to the rural livelihood of Andaman and Nicobar Islands is significant with many fishers dependent the freshwater ecosystem to meet part of their livelihood. Any significant impact due to invasive species linked to climate change will be detrimental to the island ecosystem.

5.1.1 Status of Aquatic System

Over the years, many research and development efforts were pressed in marine fisheries sector and freshwater fish diversity is ignored on large ground in terms of biodiversity, invasions and status of native fauna. It has been observed that habitat loss and destruction or disturbance to the freshwater system is more than terrestrial ecosystem (Sala et al., 2000). At the same time, the freshwater system is unique and limited by size and extent particularly with reference to small islands. It is stated that invasions by non-indigenous species have been recognised as the second most important threat to global biodiversity particularly in island ecosystem after loss of habitats and landscape fragmentation (Allendorf and Lundquist, 2003). In this regard, intense demand on inland aquaculture at Andaman Islands can possess a great threat to the freshwater biodiversity of these pristine islands.

Freshwater aquaculture plays a very important role in livelihoods of local communities. Currently, the freshwater ponds in Andaman and Nicobar Islands are more than 2500 in addition to tanks, reservoirs and small rivers. Many ponds are basically irrigation ponds and not built on context of fish farming. The production of aqua cultured freshwater fishes in Andaman Islands is said to be 85 tonnes (Rajan and Sreeraj, 2014). At present, Andaman and Nicobar Islands consists of more than 2500 minor irrigation ponds with total water spread area of 114.35 ha used for pisciculture purpose and 367 ha of reservoir area (7 numbers). According to fisheries at a glance 2011, the main fish culture areas practice are concentrated in Port Blair, South Andaman (488 ponds, 26.13 ha) and in Diglipur, North Andaman (473 ponds, 28.97 ha) and due to higher demand and for harvesting rain water number of ponds are increasing day by day. Further, freshwater fishes are known to survive in seasonal stream not so big in this island except few rivers in Great Nicobar Island. IMC, catfishes and freshwater prawn mainly contribute to the total fresh water fish production in the islands. On an average Andaman and Nicobar Island produces about 100–120 t/year of freshwater fishes, which includes aquacultured fishes as well.

Introduction of predatory and air breathing fishes like *Cl. gariepinus, Ch. striata, Notopterus notopterus* and *Pa. hypothalamus* and characins like *Pi. brachypomus* to meet the specific consumption demand of the settlers. A farm visit conducted to check alien species has revealed that 90% of the fish farmers culturing IMC and exotic carps illegally farms *Pi. brachypomus* and *N. notopterus* in a non-biosecured manner by doing free stocking in natural ponds, wetlands, which will provide great chance of escaping in the natural water bodies to a great level. The island has a previous history of culture of air breathing fishes like *H. fossilis* on experimental trial with seeds sourced from natural waters (Sarangi et al., 1995), which indicates and proves the establishment of natural breeding population of this air breathing fishes in the island habitat.

5.1.2 Diversity

Studies on freshwater fauna of Andaman and Nicobar Islands are scarce and information on fish fauna, their distribution and status is scanty and not compiled. Few studies on faunal diversity were made by early workers like Day (1870), Mukerji (1935) and Sen (1975) with the focus on Gobiids. Most comprehensive work was done by Herre (1939) who recorded 112 species of freshwater and littoral fishes. A checklist of freshwater fish species was produced by Palavai and Davidar (2009) recording 33 species and a comparison was made with Herre's checklist (1939). It showed that, freshwater fish diversity of Andaman Islands is limited due to the remoteness from mainland concluding that only eight species are known to inhabit pure freshwater and rest are euryhaline probably due to adaptation.

Major introductions of exotic fishes in Andaman and Nicobar Islands are believed to date back British rule (Rajan and Sreeraj, 2014). These alien fishes had been introduced to Andaman Islands owing to their significance as culturable food fish. Mukerji (1935) reported introduction of *Labeo rohita* fingerlings from Calcutta for culture in the ponds at Port Blair and he also believes that species like *Rasbora daniconius*, *Panchax panchax* (now as *Aplocheilus panchax*), *Ap. melastigma* (now as *Oryzias carnaticus*) and *Ophicephalus gachua* (now *as Ch. gachua*) were brought to these islands unknowingly along with the shipment of *L. rohita* fingerlings from mainland. Herre (1939) also suspects the introduction of *Or. melastigma* current name (*Or. carnaticus*) in the shipment of carp spawns from mainland.

Some species are introduced into Andaman and Nicobar Islands for consumption purposes including IMC (Catla, Rohu and Mrigal), Chinese carps (Silver carp, grass carp and common carp) and catfishes (Magur, Singhi), which are established thoroughly in aquaculture systems of Andaman and Nicobar Islands. These alien species has played an important role in development of freshwater aquaculture in Andaman and Nicobar Islands. In fact, globally the alien fish introductions are mainly for aquaculture purpose. Palavai and Davidar (2009) listed five species of freshwater fishes, which have been introduced deliberately or accidently since Herre's (1939) survey. They also reported few undescribed species of genus *Sicyopterus* and *Schismatogobius* based on their survey of freshwater streams of Andamans in 2009 indicating the unexplored status of freshwater faunal diversity of these islands. There is also a confusion on the accurate origin of the some species existing in these islands since so many alien species have been introduced, which really renders one to conclude a fish species whether it is native or non-native.

More recently, a systematic survey to document native and alien fishes of Andaman and Nicobar Islands was conducted during the year 2015–16, which yielded many new records of native and alien fishes. The inland fishes of Andaman and Nicobar Islands are represented by 8 families, 23 genera comprising of 34 species. Plate 9.1 shows some of the collected indigenous freshwater fishes. Gobiidae was the predominant order with 10 genera and 16 species followed by Eleotridae with 5 genera and 10 species. A total of 18 species of fishes and 1 species of freshwater prawn are documented in the study. Eight species of introduced fishes are well established in the native waters and rest being widely cultivated in the south, middle, north Andaman and Great Nicobar Islands (Plate 9.2). Table 9.2 shows checklist of the freshwater fishes known to exist in Andaman and Nicobar Islands. In general, most of them are introduced, carnivorous having bottom or column feeding behaviour. It has great implication for the native herbivorous species. This point to the fact that most of the introduced species are aggressive and tend to establish themselves at the cost of native species. Further, the native six species viz., *Eleotris andamensis, Microphis insularis, Aplocheilus* sp., *Rasbora* sp., *Esomus* sp. and *Channa* sp. might face severe threat from eight species viz., *H. fossilis, Ch. striata, N. notopterus, O. mossambicus, A. testudineus* and *Anabas cobojius, which* are exotic to Andaman and Nicobar Islands and documented in the streams and creeks of South, Middle and North Andaman.

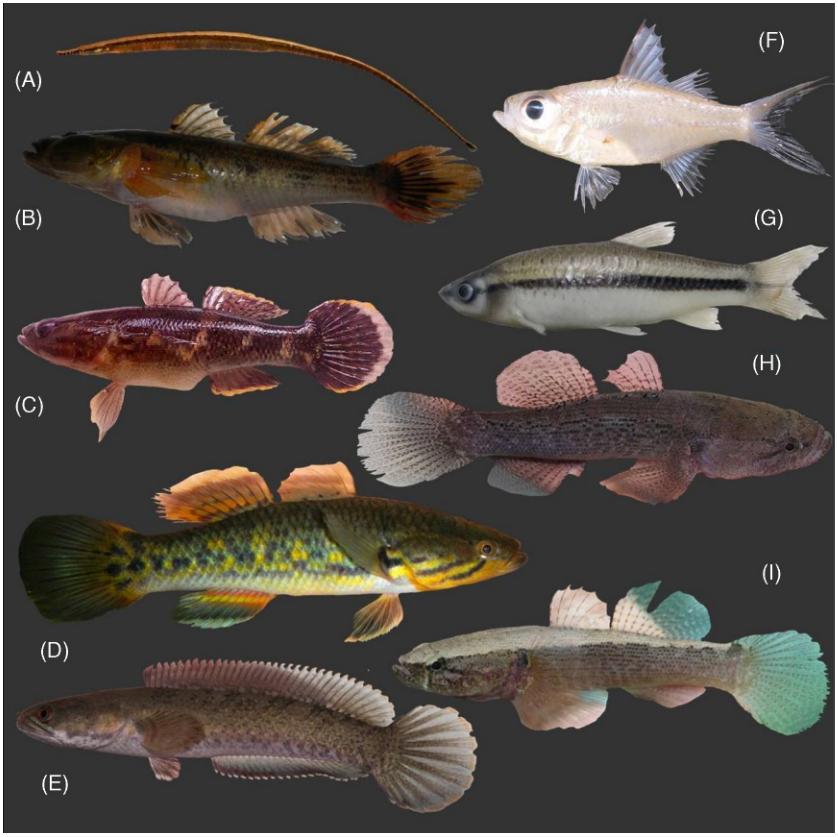

PLATE 9.1 Some of the native freshwater fishes of Andaman and Nicobar Islands. (A) *Microphis insularis*, (B) *Glossogobius giurus*, (C) *Ophiocara porocephala*, (D) *Giurus margaritacea*, (E) *Channa* sp., (F) *Ambassis urotaenia*, (G) *Rasbora* sp., (H) *Eleotris melanosoma* and (I) *Eleotris andamanensis*.

Great Nicobar Island located close to Sumatra, Indonesia recorded two introduced species *O. mossambicus*, *A. testudineus* in the streams and man-made ponds. This could be a possible human introduction by the new settlers or as a result of human activities. In Car Nicobar the freshwater source of island is mainly rainwater and it is of flat terrain. There is only a report on introduction of *Gambusia* sp. by Sunish et al. (2015) for control of malaria. During recent surveys, *Redigobius oyensi* a freshwater goby is reported for the first time from a stream at Car Nicobar Island, as it is the first record of *R. oyensi* to Andaman and Nicobar Islands.

Andaman islands are already have a good breeding population of *O. mossambicus*, which was introduced in the year 1970 for local consumption and after the 2004 tsunami these fish is said to have penetrated even creeks and other water bodies (Rajan and Sreeraj, 2013). Survey of freshwater bodies resulted in identification of good breeding population of *Ch. striata*, *A. testudineus*, *Cl. batrachus* in the ponds, creeks and dams of South Andaman, which was well established in the native waters.

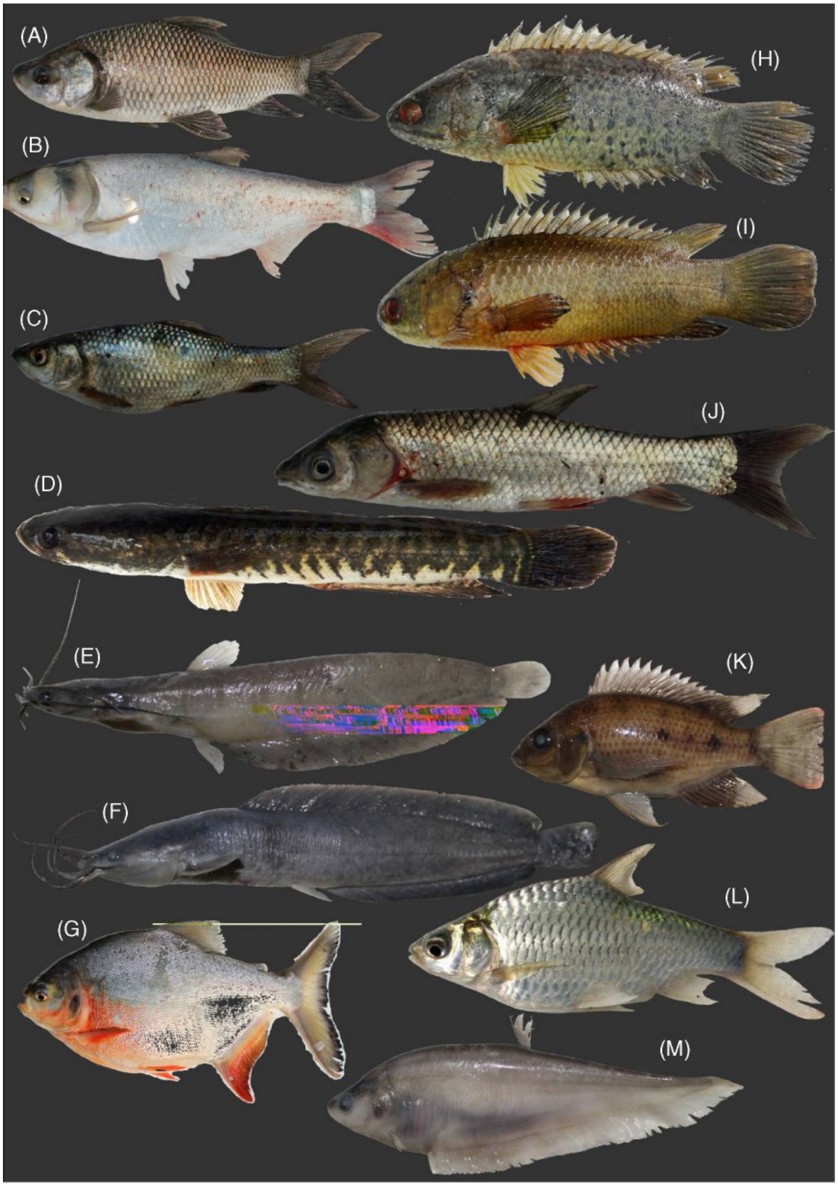

PLATE 9.2 Some of the exotic fish species in Andaman and Nicobar Islands. (A) *Catla catla*, (B) *Hypopthalmichthys molitrix*, (C) *Labeo rohita*, (D) *Channa striata*, (E) *Heteropneustes fossilis*, (F) *Clarias batrachus*, (G) *Piaractus brachypomus*, (H) *Anabas cobojius*, (I) *Anabas testudineus*, (J) *Ctenopharyngodon idella*, (K) *Oreochromis mossambicus*, (L) *Barbynomus gonionotus* and (M) *Notopterus notopterus*.

TABLE 9.2 List of Freshwater Aquatic Fauna of Native, Introduced and Unknown Origin From Andaman and Nicobar Islands

Sl. No.	Family/scientific name	Native	Introduced	Local habitat	Known feeding strata	Known feeding behavior
ANGUILLIDAE						
1.	*Anguilla bicolor* (McClelland, 1844)	•		Brackish and freshwater	Bottom	Carnivorous
2.	*Anguilla bengalensis* (Gray, 1831)	•		Brackish and freshwater	Bottom	Carnivorous
APLOCHEILIDAE						
3.	*Aplocheilus* sp. (McClelland, 1839)	•		Brackish and freshwater	Surface	Omnivorous, insectivore
CYPRINIDAE						
4.	*Rasbora* sp. (Bleeker, 1859)	•		Freshwater	Surface	Omnivorous
5.	*Esomus* sp. (Swainson, 1839)	•		Freshwater	Surface	Omnivorous
6.	*Esomus danrica* (Hamilton, 1822)			Freshwater	Surface	Omnivorous
7.	*L. rohita* (Hamilton, 1822)		•	Freshwater	Column	Omnivorous
8.	*Barbonymus gonionotus* (Bleeker, 1849)		•	Freshwater	Column	Omnivorous
9.	*Pu. sophore* (Hamilton, 1822)		•	Freshwater	Column	Omnivorous
10.	*C. idella* (Valenciennes, 1844)		•	Freshwater	Column	Herbivorous
11.	*C. carpio* (Linnaeus, 1758)		•	Freshwater	Bottom	Omnivorous
12.	*Cirrhinus mrigala* (Hamilton, 1882)			Freshwater	Bottom	Omnivorous
13.	*Hypophthalmicthys molitrix*(Valenciennes, 1844)		•	Freshwater	Surface	Planktivorous
14.	*Catla catla* (Hamilton, 1822)			Freshwater	Surface	Planktivorous
15.	*Danio rerio* (Hamilton, 1822)		•	Freshwater	All strata	Omnivorous
POECILIDAE						
16.	*Gambusia affinis* (Baird and Girard, 1853)		•	Brackish and freshwater	All strata	Omnivorous, larvivorous
ADRIANICHTHYIDAE		•				
17.	*Oryzias* sp. (Jordan and Snyder, 1906)			Brackish and freshwater	All strata	Omnivorous

(*Continued*)

TABLE 9.2 List of Freshwater Aquatic Fauna of Native, Introduced and Unknown Origin From Andaman and Nicobar Islands (*cont.*)

Sl. No.	Family/scientific name	Native	Introduced	Local habitat	Known feeding strata	Known feeding behavior
GOBIIDAE						
18.	*Glossogobius giuris* (Hamilton, 1822)	•		Marine, brackish and freshwater	All strata	Carnivorous
19.	*Psammogobius biocellatus*(Valenciennes, 1837)	•		Marine, brackish and freshwater	All strata	Carnivorous
20.	*Glossogobius celebius*(Valenciennes, 1837)	•		Marine, brackish and freshwater	Bottom	Carnivorous
21.	*Exyrias puntag* (Bleeker, 1851)	•		Freshwater and brackish water	Bottom	Carnivorous
22.	*Pseudogobiopsis oligactis* (Bleeker, 1875)	•		Brackish and Freshwater	Bottom	Carnivorous
23.	*Sicyopterus* sp. (Gill, 1860)	•		Freshwater	Bottom	Omnivorous
24.	*S. microcephalus* (Bleeker, 1855)	•		Freshwater	Bottom	Omnivorous
25.	*Bathygobius fuscus* (Ruppell, 1830)	•		Brackish and freshwater	Bottom	Carnivorous
26.	*R. tambujon* (Bleeker, 1854)	•		Brackish and freshwater	Bottom	Carnivorous
27.	*R. bikolanus* (Herre, 1927)	•		Brackish and freshwater	Bottom	Carnivorous
28.	*R. oyensi* (de Beaufort, 1913)	•		Brackish and freshwater	Bottom	Carnivorous
29.	*Schismatogobius* sp. (de Beaufort, 1912)	•		Brackish and freshwater	Bottom	Carnivorous
30.	*Awous grammepomus* (Bleeker, 1849)	•		Brackish and freshwater	Bottom	Carnivorous
31.	*Aw. ocellaris* (Broussonet, 1872)	•		Brackish and freshwater	Bottom	Carnivorous
32.	*Gobiopterus* sp. (Bleeker, 1874)	•		Brackish and freshwater	Bottom	Carnivorous
ELEOTRIDAE						
33.	*Op. porocephala* (Valenciennes, 1837)	•		Brackish and freshwater	Bottom	Carnivorous
34.	*Gi. margaritacea* (Valenciennes, 1837)	•		Brackish and freshwater	Bottom	Carnivorous
35.	*E. fusca* (Forster, 1801)	•		Brackish and freshwater	Bottom	Carnivorous
36.	*E. melanosoma* (Bleeker, 1853)	•		Brackish and freshwater	Bottom	Carnivorous
37.	*E. andamanesis* (Herre, 1939)	•		Brackish and freshwater	Bottom	Carnivorous
38.	*Butis amboinensis* (Bleeker, 1853)	•		Brackish and freshwater	Bottom	Carnivorous
39.	*B. butis* (Hamilton, 1822)	•		Brackish and freshwater	Bottom	Carnivorous

40.	*B. gymnopomus* (Bleeker, 1853)	•		Brackish and freshwater	Bottom	Carnivorous
41.	*Belobranchus belobranchus*(Bleeker, 1857)	•		Brackish and freshwater	Bottom	Carnivorous
42.	*Be. segura* (Keith et al., 2012)	•		Brackish and freshwater	Bottom	Carnivorous
CLARIDAE						
43.	*Cl. batrachus* (Linnaeus, 1758)		•	Freshwater	Bottom	Carnivorous
44.	*Cl. gariepinus* (Burchell, 1822)		•	Freshwater	Bottom	Carnivorous
HETEROPNEUSTIDAE						
45.	*H. fossilis* (Bloch, 1974)		•	Freshwater	Bottom	Carnivorous
CHANNIDAE						
46.	*Ch. striata* (Bloch, 1973)		•	Freshwater	Bottom	Carnivorous
47.	*C. punctata* (Bloch, 1973)		•	Freshwater	Bottom	Carnivorous
48.	*Channa* sp. (Scopoli, 1777)	•		Freshwater	Bottom	Carnivorous
NOTOPTERIDAE						
49.	*Notopterus notopterus* (Pallas, 1769)		•	Freshwater	Bottom	Carnivorous
CICHLIDAE						
50.	*O. mossambicus* (Peters, 1852)		•	Brackish and Freshwater	All strata	Omnivorous
ANABANTIDAE						
51.	*A. testudineus* (Bloch, 1792)		•	Brackish and Freshwater	Bottom	Carnivorous
52.	*Anabas cobojius* (Hamilton, 1822)		•	Brackish and Freshwater	Bottom	Carnivorous
SYNGNATHIDAE						
53.	*Mi. insularis* (Hora, 1925)	•		Brackish and Freshwater	Surface and column	Planktivorous
SERRASALMIDAE						
54.	*Pi. brachypomus* (Cuvier, 1818)		•	Freshwater	Column and bottom	Omnivorous
55.	*Pa. hypophthalmus* (Sauvage, 1878)		•	Freshwater	Bottom	Omnivorous
PALAEMONIDAE						
56.	*Macrobrachium rosenbergii* (De Man, 1879)		•	Brackish and Freshwater	Bottom	Omnivorous
OTHERS						
57.	*Hoplabatrachus tigrinum* (Tiger frog)		•	Freshwater	Surface	Carnivorous

Similarly breeding population of *Ch. striata*, *Cl. batrachus* and *H. fossilis* have been observed in a natural water body flowing into a creek at chouldhari village, South Andaman. Vitule et al. (2005) reports that the potential problems created by the *Cl. gariepinus* invasion as in the case of problems created by the walking catfish *Cl. batrachus*, which is a very discouraging fact, that *Cl. batrachus.* The main reason is that they are highly priced and in high demand in local markets of Andaman and Nicobar Islands. The *Ch. striata* an air breather and an ambush predator (Kottelat et al., 1993) are capable of invasion and of great biological risk to the ecology of the islands as they are carnivorous, feeding on insect's prawns, frogs and other fishes (Mohsin and Ambak, 1983).

5.2 Lakshadweep Islands

In case of Lakshadweep Islands, India located in the Arabian Sea, among 16 introduced fish species. Perciformes and Cyprinodontiformes are dominant followed by Cypriniformes, Siluriformes and Characiformes (Sirajudheen and Khan, 2014a). Further analysis by them showed that the introductions were mainly for ornamental fish culture, aquaculture and mosquito control. Sirajudheen and Khan (2014b) also reported that there are no native freshwater fishes in islands, all were introduced, and hence there is no report of threat to native fish fauna. *G. affinis* and tilapia is already discussed as worst invasive species and their impact and interaction with other aquatic organisms and ecosystem needs to be studied. The presence of alien fishes in the native waters of these islands may possess a great threat to the native aquatic fauna depending on its food, habitat and other adaptation features.

5.3 Sri Lanka

Sri Lanka is an Island nation and is biologically diverse, due to variations in topography and climate. Natural ecosystems and habitats include forests and grasslands, freshwater and marine wetlands, rivers, streams, mangroves and coral reefs. In Sri Lanka, many alien species imported for agriculture have established in the wild in low numbers, often with few recorded effects on local ecosystems. The national list of invasive alien fauna (Table 9.3) identified from this risk assessment includes seven species of freshwater fish, two species of rodents, one species of large mammal and species of molluscs. In addition, 16 species have been identified as alien fauna with a potential to become invasive (Marambe et al., 2011).

5.3.1 Direct Exploitation/Destruction of Native Species

The clown knifefish (*Chitala ornata*) is a large predator introduced in 1994. Subsequently, there have been decreases in the abundance of native fish such as *Aplochielus dayi, A. parvus, Horadandia athukorali*, *Puntius bimaculatus*, *Rasbora daniconius* and *Amblypharyngodon melettinus* (Gunawardena, 2002). The predatory walking catfish (*Cl. batrachus*) also has direct effects on native species (Weerawardane and Dissanayake, 2005). As in the case of other tropical islands the guppy (*P. reticulata*) was introduced to control mosquito larvae based on its larvivorous feeding habits, but now guppy feeding habits have become more carnivorous and the species is now feeding on the eggs of amphibians (Bambaradeniya, 1999).

TABLE 9.3 List of Invasive Alien Fauna and Their Summary Status in Sri Lanka

Species	Mode of introduction	Spread	Nature of threat	Control
Plecostomus catfish/Tank cleaner Sucker mouth catfish (*Hypostomus plecostomus*)	1994; Negligence; Ornamental fish trade	Coastal flood plain, mainly around Colombo, Gampaha, Kandy and Kalutara districts	Superior competitors for resources Scrape feeding habits-change the habitat quality	Not available
Mosambique tilapia (*O. mossambicus*)	1952; Deliberate; Commercial fishery	Island wide	Superior competitors for resources	Not available
Clown knife fish (*Chi. ornata*)	1994; Neglect; Ornamental fish trade	Coastal flood plain Streams and reservoirs – wet zone	Direct exploitation or destruction of native species	Not available
Guppy (*P. reticulata*)	1930; Deliberate; Mosquito control	Lowland wet zone, and more riverine areas – upper catchments of Mahaweli and Kelani rivers	Direct exploitation or destruction of native species	Not available
Walking catfish (*Cl. batrachus*)	Negligence; Ornamental fish trade	Marshes and streams – lowland wet zone	Direct exploitation or destruction of native species	Not available
Western mosquito fish (*G. affinis*)	Deliberate; Mosquito control	Marshes, ditches and streams of the lowland wet zone	Not known	Not available
Carp (*C. carpio*)	1915; Deliberate; Commercial fishery	Headwater streams 1500 m a.s.l. elevation	Superior competitors for resources; feeding habits-change the habitat quality; direct exploitation or destruction of native species	Not available
Giant African snail (*Lissachatina fulica*)	1840; Negligence, research/hobby	Island wide distribution in natural and managed terrestrial habitats	Pest of agricultural landscapes	Chemical control – metaldehyde

Source: Adapted from Marambe, B., Silva, P., Ranwala, S., Gunawardena, J., Weerakoon, D., Wijesundara, S., Manawadu, L., Atapattu, N., Kurukulasuriya, M., 2011. Invasive alien fauna in Sri Lanka: National list, impacts and regulatory framework. In: Veitch, C.R., Clout, M.N., Towns, D.R. (Eds.), Island Invasives: Eradication and Management. IUCN, Gland, Switzerland, pp. 445–450.

5.3.2 Competitors for Resources

In Sri Lanka, Mosambique tilapia (*O. mossambicus*) is non-selective in its diet and breeds prolifically, enabling it to colonise tanks, reservoirs and slow flowing rivers while displacing native inhabitants such as *L. porcellus* and *L. dussumieri* (Pethiyagoda, 1999). The diet of small tilapia comprises zooplankton, which are food resources for indigenous fish. The endemic red-fin labeo (*L. lankae*) overlaps in distribution with tilapia and has been driven to near extinction, possibly due to this competition (Pethiyagoda, 1999). *Mozambique tilapia* also occupies the same habitats as the indigenous cichlid *Etroplus suratensis*, and the two species probably compete for nesting space. The listing of *M. tilapia* as an IAS was challenged by aquaculture specialists who claimed that endemic fish species do not exist in the reservoirs where tilapias are abundant (Amarasinghe et al., 2006). Populations of *M. tilapia* that established in some non-flowing habitats showed little significant dietary overlap with indigenous fish species. These contradictory views indicate that the impact of co-occurring populations of tilapia and indigenous fish is not clear and further assessment is warranted (Marambe et al., 2011).

In recent times, increased fishery pressure and the adoption of harmful fishing practices (i.e. small-meshed gill nets) to catch exotics such as tilapia and carp (*C. carpio*) have impacted non-target species such as freshwater turtles in the dry zone reservoirs (Pethiyagoda, 1999).

5.4 Pacific Island Countries

Freshwater fishes, amphibians and crustaceans have been introduced to Pacific islands for aquaculture, sport, improvement of wild stock, the aquarium trade and biological control.

A total of 86 species of fish have been introduced into fresh (some brackish) waters in the Pacific and Hawaiian islands; not all of these introductions have been successful. A total of 72 fish species have been introduced into the Hawaiian islands, and 59 have been observed or established since 1982. 20 of the 59 are aquarium species. Papua New Guinea has received 30 species with 19 being considered established. Werry (1998) reported four species recently (between 1993 and 1997) introduced to Papua New Guinea for stock enhancing (*Colosoma bidens*, *Tor putitora*, *Acrossothedus hexagonocheilus* and *Schizothorax richardsonii*); they are not yet established. Guam and Fiji each have 24 species introduced, 12 species established on Fiji and 17 species established on Guam. New Caledonia has eight established species; three previously reported are no longer found. Several species of the families Cichlidae (tilapia) and Poeciliidae (livebearers) have been introduced and many have become naturalised (Fig. 9.3). Comments pertaining to these families are separated below, since many of the above-listed ecological impacts have been reported for these species.

In addition to the fishes, the marine or cane toad occurs naturally from southern Texas and western Mexico to central Brazil (Zug and Zug, 1979). Because of their large size and wide adaptability, these toads were thought to be good biological control agents, primarily for insects. They have been introduced throughout much of the Pacific area during the past 50 years and are now considered one of the most widespread terrestrial vertebrates (Easteal, 1981). A small frog *Litoria fallax* (Peters, 1881) was first found in the central courtyard of the then Guam International Airport in 1968 (Eldredge, 1988). This species, native to southern Queensland, has spread throughout Guam and is associated with wetlands (McCoid, 1993).

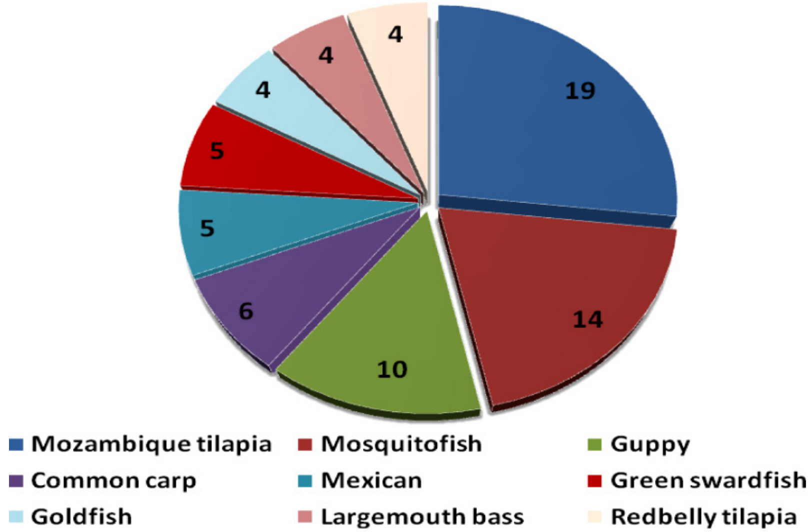

FIGURE 9.3 **Introduction of non-native species into Pacific islands.**

Another hylid frog, the green and golden bellfrog (*Litoria aurea*; Lesson, 1830) was also introduced to New Caledonia more than a century ago, several amphibians have been introduced to the Hawaiian islands. Bullfrogs (*Rana catesbeiana*) Shaw (1802), were initially brought to Hilo, Hawaii, between 1879 and 1899 as a source of food and as a biological control agent for introduced aquatic invertebrates (McKeown, 1996). The freshwater crustaceans of the Pacific islands have not been comprehensively investigated. The giant Malaysian prawn *Macrobrachium lar* (Fabricius, 1798) and the giant freshwater prawn (*Ma. rosenbergii* (De Man, 1879)) belong to the crustacean family Palaemonidae. Their distribution is restricted, *Ma. lar* being found in the Indo–Pacific. Specimens of *Ma. rosenbergii* were imported to Hawaii to develop mass rearing techniques, beginning with 36 individuals from Malaysia in 1965. Similarly the freshwater crayfish (red swamp crawfish) *Procambarus clarkii* (Girard, 1852) was first introduced into Hawaii in 1923 and 1927 (Brock, 1960).

5.5 Caribbean Islands

The Caribbean region is regarded as one of the world's biodiversity 'hotspots' (Myers et al., 2000). The occurrence of invasive species problems in the Caribbean region has increased in recent years, and is likely to increase further, as a consequence of expanding global trade and increased international movement of humans, biological material and other commodities. However, capacity to tackle invasive species issues at a national level varies considerably amongst the countries of the insular Caribbean. The list of species reported alien, or naturalised/invasive was dominated by terrestrial species, which includes 479 alien, 390 naturalised or invasive. Marine species made the smallest contribution to the list (16 species naturalised/invasive, 4% of the total naturalised/invasive list). Among different groups there were 34 fishes described as exotic and 35 are naturalised and/or invasive. Table 9.4 provides a list of invasive/exotic freshwater fishes found in the Caribbean islands (Kairo and Ali, 2009).

TABLE 9.4 A List of Species Reported Exotic, Naturalised or Naturalised and Invasive in the Caribbean

Species name	Common names	Exotic in	Naturalised and invasive in
Betta sp.	–	Dominican Republic (DR), Haiti	–
Betta splendens	Betta, Siamese fighting fish	Dominican Republic	Dominican Republic
Copello arnoldi	Splashing tetra	Trinidad	Trinidad
C. carpio	Carpa (DR)	Dominican Republic	Dominican Republic
Dorosoma petenense	Threadfin Shad	Dominican Republic	Dominican Republic
G. affinis	Pez mosquito (DR), western mosquito fish	Dominican Republic	Dominican Republic
G. holbrooki	Pez mosquito (DR), eastern mosquito fish	Dominican Republic	Dominican Republic
I. punctatus	Pez gato (DR), Channel Catfish	Dominican Republic	Dominican Republic
Lebistes reticulatus	Guppy	Dominican Republic	Dominican Republic
Micropterus salmoides	Lobina-truche (DR), Largemouth Bass	Dominican Republic	Dominican Republic
O. mykiss	Trucha arco iris (DR), rainbow trout and steelhead trout	Dominican Republic	Dominican Republic
O. aurea	Tilapia aurea (DR), Blue tilapia	Dominican Republic	Dominican Republic
O. hornorum	Tilapia hornorum (DR)	Dominican Republic	Dominican Republic
O. mossambicus	Tilapia mossambica (DR)	Dominican Republic	Dominican Republic
O. niloticus	Tilapia nilotica (DR)	Dominican Republic, US Virgin Islands	Dominican Republic
Oreochromis sp.	Tilapia rojo (DR)	Dominican Republic	Dominican Republic
O. urolepis	Tilapia, Rufigi tilapia	Bahamas Islands	Bahamas Islands
P. latipinna	Sailfin molly	Dominican Republic, Bahamas Islands	Bahamas Islands, Dominican Republic
P. reticulata	Guppy	Dominican Republic, Haiti	Dominican Republic, Haiti
P. sphenops,	Liberty Molly	Trinidad	Trinidad
Salmo gairdneri	Rainbow trout	Dominican Republic	Dominican Republic
Oreochromis mossambicus	Tilapia mosambica (DR)	Dominican Republic	Dominican Republic
Sarotherodon niloticus	Tilapia nilotica (DR)	Dominican Republic	Dominican Republic
Serrasalmus natterei	Black piranha	Barbados	
Tilapia sp.	Tilapia	Dominican Republic, Haiti	Dominican Republic, Haiti
Trichopodus trichopterus	Gurami (DR), Blue Gourami	Dominican Republic	Dominican Republic
Xiphophorus helleri	Colaspada (DR)	Dominican Republic	Dominican Republic
Xi. maculatus	Platy	Dominican Republic	Dominican Republic
O. placidus	Black tilapia	Barbados	Barbados

(Exotic = known to be present in the Caribbean in cultivation, captivity or in the wild. Naturalised = known to be established in the wild in at least one Caribbean country. Invasive = established in the wild and reported to be spreading, and/or regarded as a threat to a native species, ecosystem or causing a socioeconomic impact.)

Eradication programmes are expensive and in many cases very difficult as for as islands are concerned due to its unique ecosystem. Therefore, early detection and control of species invasions are more likely to prove effective and sustainable. There is a need to build on existing facilities wherever possible, and to broaden the scope of regulations and their implementation beyond purely agricultural concerns.

Global experience suggests that two particular obstacles in such a process are a lack of baseline information on invasive species, and a low level of awareness of the threats that they represent. Awareness needs to be raised at all levels of society, from public to policy-makers. A particular challenge arises from the fact that many of the major pathways for species introductions are critical to national economies.

6 IMPACT OF INVASIONS

6.1 Aquatic Diseases

Invasive species and intentional species introduction may cause potential transmission of diseases, which may be new to the ecosystem. They also possibly carry new parasitic infestations, which may also establish in the ecosystem. The *Ch. striata* are also a well known carrier of EUS and experimental demonstration of the cohabitation of an infected specimen along with healthy ones induced EUS had been demonstrated by Cruz-Lacierda and Shariff (1995). *Ch. striata* is also a carrier of virus and potentially harmful pathogens like Birna viruses had been isolated from it by Saitanu et al. (1986). The *Ch. striata*, which is well established in South Andaman and North Andaman were collected from stream flowing into creeks from a particular location in South Andaman. This could be a potential danger for the fishes and prawns inhabiting creeks and also for euryhaline species.

The carnivorous *Cl. gareipinus* (African catfishes) cultured by some farmers in South and North Andaman could be a top most predator in the native waters. In the mainland India, the union agriculture ministry has issued order to kill the fish by angling but this has proved ineffective to control them. When non-native species are introduced into a new range then their parasite fauna can also be introduced and there is a chance of potentially spilling-over into native hosts (Williams et al., 2013). The monogenean parasites with direct lifecycles with no intermediate hosts can invade the native species and colonise them (Jimenez-García et al., 2001). All the listed air breathing fishes like *Ch. striata*, *A. testudineus*, *H. fossilis*, *Cl. batrachus* and *Ch. punctata* are known carriers of trematodes like *Astiotrema reniferum* and *Genarcopsis goppo* as reported by Puinyabati et al. (2010). Biu and Akorede (2013) conducted a study on prevalence of endoparasites of *Cl. gariepinus* using standard parasitological methods in Nigeria and found that 38% of examined fishes were infected with parasites such as nematodes, cestodes and protozoa. Invasive species may introduce novel pathogens to a colonised area (Bacela-Spychalska et al., 2012). A list of pathogens from exotic fishes is discussed in Table 9.5. Also a data on freshwater fish and prawn diseases reported in Andaman and

TABLE 9.5 Freshwater Fish and Prawn Introduced in ANI and the Diseases Reported in Mainland India

Species	Disease type	Reported diseases	References
Indian major carps	Bacterial	BKD, dropsy, fin and tail rot, ulcerative disease, edwardsiellosis, columnaris, bacterial gill disease	Karunasagar et al., 1986; Mastan and Ahmed, 2013; Mukherjee et al., 1994; Verma and Rathore, 2013; Vineetha and Abraham, 2009; Swain et al., 2003
	Fungal	EUS, saprolegniasis, gill rot and mycotic infections	Gopalakrishnan, 1966; Jhingran and Pullin, 1985; Pachade et al., 2014; Pradhan et al., 2014
	Parasitic	Argulosis, lerneaosis, myxoboliasis, gyrodactylosis, dactylogyrosis, trichodiniasis, costiasis, ichthyophthiriasis, whirling disease, black spot disease, acanthocephalan infestation, nematode and chilodonella infestation	Dash et al., 2015a; Ganapati and Rao, 1962; Maheswari, 1986; Mukherjee, 2002; Ramudu et al., 2016; Vineetha and Abraham, 2009
Chinese major carps	Bacterial	Eye disease, gill hyperplasia syndrome, haemorrhagic septicaemia and fin rot	Harikrishnan et al., 2003; Khatri et al., 2009; Kumar et al., 1986; Parvez and Mudarris, 2014; Shah and Tyagi, 1986
	Fungal	Gill rot, saprolegniasis	Jhingran and Pullin, 1985; Khatri et al., 2009
	Parasitic	Black spot disease, ichthyophthiriasis, costiasis, argulosis, trichodiniasis, myxoboliasis, acanthocephalan infestation, nematode and chilodonella infestation, monogenean, piscinoodinium and copepod parasite infestations, epistylis, vorticella and zoothamnium infestations	Dash et al., 2015b; Kaur and Katoch, 2016; Khatri et al., 2009; Mukherjee, 2002; Ramesh et al., 2000; Singh and Kaur, 2014; Tantry et al., 2016
Catfishes	Bacterial	Haemorrhagic septicaemia, columnaris and dropsy and edwardsiellosis	Lipton, 1994; Prasad et al., 2011; Sahoo et al., 1998; Singh and Lakra, 2011a,b
	Fungal	EUS, saprolegniasis, fusarium infection, mycosis and mycotic infections	Bisht et al., 2000; Khulbe et al., 1994; Mastan, 2015; Pachade et al., 2014; Pradhan et al., 2014
	Parasitic	Trichodiniasis, myxoboliasis, trypanosomiasis, intestinal cestode infestation, acanthocephalan infestation, gyrodactylosis, dactylogyrosis and nematode infestation	Bose and Sinha, 1985; Gambhir, 2014; Mukherjee, 2002; Singh and Kaur, 2012; Singh and Lakra, 2011a,b; Singh and Lakra, 2012; Tandon and Joshi, 1973
Murrels	Bacterial	Eye disease, haemorrhagic septicaemia and vibriosis	Ganesh et al., 2012; Jhingran, 1991; Parvez and Mudarris, 2014

TABLE 9.5 Freshwater Fish and Prawn Introduced in ANI and the Diseases Reported in Mainland India (*cont.*)

Species	Disease type	Reported diseases	References
	Fungal	EUS, saprolegniasis, fusarium infection and mycotic infections	Bisht et al., 2000; Mukherjee, 2002; Pachade et al., 2014; Shrivastava and Shrivastava, 1977
	Parasitic	Trematode infestation, ichthyophthiriasis, myxoboliasis, trypanosomiasis, acanthocephla infestation and cestode infestation	Gupta and Jairajpuri, 1982; Kaur et al., 2012; Kaur and Shrivastav, 2012; Kalavati and Narasimhamurti, 1985; Lipton and Lakshmanan, 1985; Reddy and Benarjee, 2011; Shareef and Abidi, 2012
Cichlids	Bacterial	Haemorrhagic septicaemia, edwardsiellosis and vibriosis	Bhanumathi et al., 2010; Miyashita, 1984
	Fungal	Fusarium infection, mycotic infections	Mastan, 2015; Pillai and Freitas, 1983
	Parasitic	Trypanosomiasis, nematode, cestode, trematode, piscinoodinium and acanthocephalan infestations	Mandal, 1976; Nimbalkar et al., 2010; Ramesh et al., 2000
Freshwater prawn	Viral	White tail disease and white spot syndrome	Hossain et al., 2001; Sudhakaran et al., 2007; Walker and Winton, 2010
	Bacterial	Vibriosis and shell disease	Jayasree et al., 1999; Khuntia et al., 2008
	Fungal	Mycotic infections	Shah et al., 1977
	Parasitic	Zoothamnium, epistylis, gregarina, amphileptus, dileptus, myxobolus, chilodonella, balladyna, gozia, rhabdochona, indocucullanus, procamallanus, acineta, vorticella, gregarines, cucullanus, cestode, nematode and isopod infestations	Jayasree et al., 2001; Paul et al., 2010
Ornamental fishes	Viral	Carp edema virus infection and cyprinid herpesvirus-2 infection	Sahoo et al., 2016; Swaminathan et al., 2016
	Bacterial	Haemorrhagic septicaemia, dropsy, fin and tail rot, ulcerative disease, columnaris, myxobacterial infection and streptococcal infection	Citarasu et al., 2011; Chidambaram et al., 2014; Sreedharan et al., 2013; Verma et al., 2015
	Parasitic	Ichthyophthiriasis, trypanosomiasis, arguluosis, trichodiniasis, dactylogyrus, gyrodactylus, procamallanus and cucullanus infestation	Chanda et al., 2011; Gupta et al., 2003; Saha and Bandyopadhyay, 2016

ANI, Andaman and Nicobar Islands; *BKD*, Bacterial kidney disease; *EUS*, epizootic ulcerative syndrome.

Nicobar Islands and adjoining nations is given in Table 9.6. It is known that Andaman and Nicobar Islands is known to be free from much aquatic disease. To increase the aquaculture production and local consumption, freshwater fishes are regularly brought to Andaman and Nicobar Islands. Therefore, Singh and Lakra (2011a,b) recommended that effective quarantine

TABLE 9.6 Freshwater Fish and Prawn Diseases Reported in Andaman and Nicobar Islands and Adjoining Nations

Aquatic animal diseases	Indonesia[a]	Thailand[b]	Malaysia[c]	Sri Lanka[d]	Myanmar[e]	India[f]	Andaman and Nicobar Islands[g]
Viral diseases							
KHV disease	+	+	+	#	×	×	×
SVC	×	×	×	×	×	×	×
White tail disease	+	+	+	#	#	+	×
Bacterial diseases							
Haemorrhagic septicaemia	+	#	+	+	+	+	×
Abdominal dropsy	+	+	#	+	+	+	+
Edwardsiellosis	+	+	+	#	#	+	×
Parasitic diseases							
Ich or white spot disease	+	+	+	+	#	+	×
Trichodiniasis	+	+	+	+	#	+	×
Lernaesis	+	+	+	+	+	+	×
Argulosis	+	+	+	+	+	+	+
Gill and skin fluke infection	+	+	+	+	+	+	×
Fungal diseases							
EUS	+	+	+	+	+	+	×
Saprolegniasis	+	+	#	+	+	+	×

+, Disease reported; ×, disease not reported; #, information not available; *EUS*, epizootic ulcerative syndrome; *KHV*, Koi herpesvirus; *SVC*, spring viremia of carp.

[a] *Bondad-Reantaso et al., 2005; Chitmanat et al., 2005; Maskur, 2013; Muchlisin et al., 2014; Sunarto et al., 2004*.

[b] *Bondad-Reantaso et al., 2005; Chitmanat et al., 2005; Chukanhom and Hatai, 2004; Kanchanopas-Barnette et al., 2009; Kasornchandra et al., 1987; Kumnerdphol and Purivirojkul, 2009; Leong et al., 1987; Tasawar et al., 2009; Willoughby et al., 1995*.

[c] *Bondad-Reantaso et al., 2005; Bu and Seng, 1997; Lourelle and Oldewage, 2009; Musa et al., 2009; Sayuthi, 1993; Son et al., 1997*.

[d] *Bondad-Reantaso et al., 2005; Costa and Wijeyaratne, 1989; Karunarathne and Sundharabarathy, 2011; Mukherjee, 2002; Thilakaratne et al., 2013; Vinobaba, 1991*.

[e] *John and George, 2012; Kitancharoen et al., 1995; Mohan and Phillips, 2005; Roberts, 1997*.

[f] *Bhuiyan et al., 2008; Bondad-Reantaso et al., 2005; Hameed et al., 2004*.

[g] *Shome, 1999; Shome et al., 1996*.

measures are required to prevent exotic pathogens and parasites as aquarium fish trade and fish introductions are likely to increase in future.

6.2 Food Source

As most of the island hill streams, rivulets and ponds are almost maintaining perennial flow due to heavy rainfall, there is more risk of this species invading all water bodies and completely eradicating the native aquatic biodiversity as they can instinctively move to a new body of or across land once food becomes scarce, which puts all waters at risk for invasion. The introduced *Pi. brachypomus* was said to be introduced from Bangladesh at Kolkata, Mainland India in the year 2003 and 2004 (Chattarjee and Mazumdar, 2009). In the mainland India, aquaculture of this species is been carried out under the name 'Red pomfret or freshwater pomfret' and had paved way for its establishment of population in various rivers across India viz., Tripura (Datta and Nandeesha, 2006), Maharashtra (Singh and Lakra, 2011a,b) and Chalakuddy river, Kerala (Dahanukar et al., 2011). Now aquaculture of this species is being carried out in the South and North Andamans as well. These species possesses powerful dentition that can cause serious bites to humans and fishes (Robins et al., 1991). Because of the unregulated aquaculture practices and import of illegal fish seeds from Kolkatta by farmers, the fate of the island ecosystem is really under threat. There are less than 300 exotic species traded in India and there is a lack of data of their impact on ecology (Knight, 2010).

The introduced *Pu. sophore* can also have an habitat threatening situation since the fingerling stage of it prefers mostly picoplanktonic food of animal origin and the adult stage gut content analysis shows Chlorella, pico-planktonic biota, zooplanktonic biota, broken fish and prawn (Banik and Saha, 2013), this feeding behaviour of the barb can deprive of the food available for the native genus like of Gobiidae where they dominate 70% of freshwater fish families found in Andaman and their gut content analysis shows zooplanktons, small insects, invertebrate and other fish fries. This situation of biological invasion will definitely have an impact on the food chain of the native species. Even the Nicobar Islands has the reports of large scale introduction of *G. affinis* for mosquito control at the Car Nicobar Island, which is a part of Nicobar Island group (located at 9.16°N, 92.75°E) by the Malaria Research Centre under the *aegis* of Indian Council of Medical Research, India (Sunish et al., 2015). The *Gambusia* sp. in many instances turns to be a predator (Rinne, 1995) and its introduction threatened many native cyprinodonts in Europe and North America (Elvira, 1990). *G. affinis* also shown to compete strongly with endemic species in several water bodies of Greece (Economidis, 1995). A list of introduced fishes and their possible impacts has been discussed in Table 9.7.

7 CONSERVATION

Biological invasions are increasingly influencing ecosystems all over the world (Velde et al., 2009) and their impacts are to be studied on priority for conservation and management of biodiversity. Alternatively some of the alien species in the new aquatic environment may be a good source of food and provide other useful services to the ecosystem. This aspects needs to be considered because many of the existing species might have come from elsewhere during the evolutionary period.

TABLE 9.7 Impact of Introduced Alien Fishes in India

Species	Native	Purpose of introduction	Case location	Impact	References
G. affinis, G. holbrooki (mosquito fish)	Italy	To control mosquito larvae	Maharashtra Lake Nainital	Feeding on eggs of fish eggs, competition for food and space and affecting the population of native fishes	Knight, 2010; Nirmal and Gupta 2016; Praveenraj, 2014
Pterygoplichthys pardalis (sucker mouth catfish)	South America	Ornamental fish trade	Telangana, Kerala	Habitat modification, siltation and voracious feeder	Biju Kumar; Rao and Sunchu, 2017
Cl. gariepinus	Africa	Illegal introduction for aquaculture	Kerala, Telangana	Voracious feeder, threat to native fish, bird and reptile diversity	Krishnakumar, 2011; Mahender 2015
Oreochromis sp. (tilapia)	Africa	Aquaculture	Telangana, Kerala	Prolific breeder, compete for food and space	Biju Kumar, 2013; Mahender, 2015
Hy. molitrix (silver carp)	Hong Kong	Aquaculture	Gobindsagar Reservoir (Himachal Pradesh)	Has completely replaced the native fish *C. catla*	FAO Technical Paper 345
Hybrid tor species (orange fin Mahseer)	India (translocated)		Karnataka and Tamil Nadu (Cauvery river)	Replace the native humpback (bluefin mahseer) *Tor khudree*	A.J.T. Johnsingh, NCF, Mysore and WWF, India
Exotic trout	United Kingdom	Angling and aquaculture	Jammu and Kashmir	Replace the native Indian snow trout's	
P. reticulata (guppy)	South America	Aquarium and mosquito control	Maharashtra	Feeding on eggs of fish eggs, competition for food and space and affecting the population of native fishes	Knight, 2010; Praveenraj, 2014
A. testudineus (climbing perch)	Thailand	–	Maharashtra	Destruction of native fish, bird and reptile biodiversity	Paliwal, 2014

7.1 Alternative Ways of Management

It is reported that overall alien finfish species have done little ecological harm to native flora and fauna (De Silva et al., 2006). Alien finfishes have also shown tremendous impact on the livelihood of Asian fishers. However, they may have a short-term positive effect on livelihood sector and a long-term harm on native ecosystem. In Chile, the aquaculture production is mainly contributed by exotic salmon (Gajardo and Laikre, 2003). In India too, alien fishes has brought both positive and negative effects to the nature and livelihood. In Andaman and Nicobar Islands, the livelihoods of many fishers were depending on the introduced alien fishes and still the marketing communities are hugely dependent on the fishes being brought from mainland to satiate the local demand and their livelihood. Hence, in present context it's very difficult to eradicate the alien fish population. However enforcement of strict screening through routes, certification from transporting authorities, stringent laws in bringing live alien fishes, quarantine check, unintentional introductions can be checked thoroughly.

The freshwater fish fauna of Andaman represent mainly Gobiids, which have a great potential for freshwater aquaculture and aquarium hobby. The families like Eleotrids are capable of growing to 20 cm (FAO, fact sheets) and sought after by the natives of Andaman Islands. There is a great scope for induced breeding trails of this native gobies as done on other goby species like *Oxyeleotris marmorata* (marble goby) in the South East Asian countries, which is considered as a high value fish (Tan and Lam, 1973) necessitating conservation. Similarly the species like *Glossogobius giurius, Gl. celebius, Giuris margaritacea, Ophiocara porocephala* may evolve as a good candidate species for the island freshwater aquaculture as well as for ornamental trade. Ninety percent of the freshwater ornamental fishes exported from India are wild caught indigenous species (Silas et al., 2011). Similarly the native species like *Gi. margaritacea, Sicyopterus microcephalus, Channa* sp., *R. tambujon, R. bikolanus, R. oyensi, Stenogobius gymnopus, Scatophagus argus, Schismatogobius* sp. and *Toxotes jaculator* has a good aquarium value and currently being traded. Breeding of this species will evolve as a good source of income for the local people and this may indirectly contribute in the conservation of the species. A very good example of this fact is some of the fish species traded in the aquarium hobby are highly threatened in wild but are well established in the aquarium trade since many of such species are mass bred in various farms across the world. A typical example for this is *Epalzeorynchus bicolor* and *Yasuhikotakia sidthimunki* (Kottelat et al., 2012). Similarly the *Sahyadriya denisonii* (*Red line torpedo barb*) from India, which is assessed endangered by Ali et al. (2015) are commercially bred and are being exported from Indonesia and Singapore (Mittal, 2009). The native freshwater prawns belonging to the family Atyidae also have a very good ornamental value and gaining popularity in the aquarium industry over the years (Heerbrandt and Lin, 2006). The *Caridina* spp. is known for its coloration and an excellent scavenger of unwanted algae in a planted aquarium tanks (Thomas and Jayachandran, 2007) and prawns like *Macrobrachium latimanus, Ma. Gurudeve, Ma. Ornatus, Ma. Idella* and *Caridina Natarajani* are also been introduced in aquarium by Jayachandran (2006a,b) for ornamental purpose. The Andaman Islands with a reported seven species of Caridina and six species of *Macrobrachium*, can be potential candidate animals for ornamental hobby and aquaculture.

Interestingly alien fishes are also seen as reliable indicator of river health with some provisos (Kennard et al., 2005) and invasions by exotic species does not necessarily lead to extinction or imperilment of many native species (Gido and Brown, 1999). Many times exotic fishes are introduced just by virtue of their production capabilities, wherein their influence on the ecosystem, interaction with the species and biology is not clearly known. For these reasons it is wise to conserve either in the field or aquarium some of the harmless species for economic benefit.

7.2 Quarantine and Biosecurity

Much of attention on introduction and ill effects of alien species were realised in recent days. In case of India, the mode of entry is multiple and is difficult to control the spread of fishes in a territory. However, an island ecosystem is completely cut-off through sea where modes are through air or water. These modes of transport can be effectively managed and could be kept in control. A quarantine and biosecurity system can be established, which can screen the exotics, the diseases probably spread by them and other parasites and amphibians associated in the transport. Strictly controlled introductions (Raman et al., 2013) would best possible way to control further expansion of alien species in islands. Control techniques available for aquatic invasive species are time and labour intensive, expensive and often lethal for non-target species (Kapuscinski and Sharpe, 2014). Hence formulating best possible ways to mitigate further spread could be best followed rather than attempts to eradicate invasive fish species.

Nicobar group of islands like many other tropical islands is cut-off from larger island groups and transport routes are through sea depending on weather and other conditions. Though the effects of alien fishes could be irreversible in many islands, in several isolated islands like Great Nicobar and Lakshadweep could still be contained and controlled since the freshwater fish farming is not an major livelihood activity since the islanders are primarily tribals and their livelihood are depending on plantation crops and marine fisheries. Industrial and domestic pollution are known as most serious factor threatening freshwater fishes but in several tropical islands major industrial activities are limited and discharge of effluents into freshwater are negligible. Domestic pollution also could not be seen as a major threat considering the level of urbanisation in these islands. The one major threat to indigenous freshwater fishes will only be the invasive alien fishes coming to islands for food and business.

7.3 Aquarium and Labeling

The Inland waters and freshwater diversity is a treasure house for valuable natural resource, in terms of cultural, educational, aesthetic, and scientific and economics (Dudgeon et al., 2006). But, invasive non-native species represent a major threat to biodiversity worldwide (Tinsley et al., 2015). Singh, (2014) suggests that aquarium fish trade is undeniably a vector activity that has role in introduction, dispersal and invasion of exotic species. Therefore, it is very important to protect and save the biodiversity to sustain them on a long run. Though management and control of non-indigenous species is biggest challenge for any conservation biologists (Allendorf and Lundquist, 2003), the best measure is to save the vanishing native species by breeding and reintroduction.

Another worst scenario is chances of hybridisation between alien and native species, which could lead to genetic erosion of native taxa (Pliszko and Zalewska-Galosz, 2016). Particularly in islands, hybridisation with IAS can be threat to rare species thereby diluting the native gene pool to point of extinction (Reaser et al., 2007). The conservation of aquatic germplasm resources is to be taken on priority in the present global scenario where more fish species are being reported to be endangered or threatened (Lakra et al., 2010). Alien species pose several challenges for future management of freshwater ecosystems (Strayer, 2010) and immediate measures are to be addressed to control further aggravation of the issue. Considering the negative impact of exotic fishes on aquatic biodiversity, stringent regulations are to be framed regarding the import of non-native species (Kumar, 2000).

Import risk analysis and the hazard analysis critical control point are measures suggested by Cagauan (2007) to control invasive species. Such import risk analysis could be very relevant in island ecosystems and managing the entry points also will be easier. Islands normally will have limited resources in terms of agricultural, animal and fishery products for consumption and they will be mainly dependent on adjoining countries import. Though indigenous fishes are available, they do not contribute for consumption purposes and in Andaman and Nicobar Islands the consumption requirement is completely managed by introduced fishes. Other than the natural phenomenon, which displaces the fish population from one region to other, introduction of alien exotics intentionally creates severe issue with permanent damage. Many times their consequences are not visualised by the farmers who introduce them in their aquaculture ponds in name of diversification without understanding the biology and behavior of species. Transfers and introduction of species from one hydrographical location to other is increasing and with risk of introduced diseases is also manifesting with all ferocity (Raman et al., 2013). On the other hand nothing can be done to eliminate the already established exotics that have a much localised distribution (Courtenay et al., 1974). Controlling invasive species could be a very tough task though some interesting concept of genetic biocontrol is yet to be put in practice (Kapuscinski and Sharpe, 2014).

8 CONCLUSIONS

The comparative analysis of past introductions could be major approach to study the effect of invasive species and effective vector should be coupled with efforts to improve environmental conditions to minimise invaders success within ecosystem. Particularly in island ecosystem it is difficult to predict the vulnerability due to IAS and it is necessary to establish and standardise databases on Inland water organisms and associated environmental information (Fu et al., 2003). Measures to control alien species is to exploit them commercially for food and to formulate a strict legislative rule for unregulated aquaculture practices and to have a thorough checking of the consignment both at airport and harbor for alien, exotic species and intensifying studies on the impacts of invasive species on native ecosystems in the islands.

Eradicating or managing IAS in tropical islands requires a coordinated strategy based on cooperation among all land managers, national and international agencies concerned with it. The situation created as a result of expanding international trade, tourism, transport besides climate change has facilitated the entry to, and spread of, IAS through new pathways.

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