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Felegush Erarto
Bahir Dar University, College of Agricultural and Environmental Sciences, School of Fisheries and Wildlife Management, Department of Fisheries and Aquatic Sciences, P.O. Box 5501, Bahir Dar, Ethiopia

Abebe Getahun
Addis Ababa University, College of Natural Sciences, Department of Zoological Sciences. P.O. Box 1176, Addis Ababa, Ethiopia

Corresponding Author:
Felegush Erarto
Bahir Dar University, College of Agricultural and Environmental Sciences, School of Fisheries and Wildlife Management, Department of Fisheries and Aquatic Sciences, P.O. Box 5501, Bahir Dar, Ethiopia

Impacts of introductions of alien species with emphasis on fishes

Felegush Erarto and Abebe Getahun

Abstract
Invasive alien species affect native species both indirectly for example, by preying on and competing with them for resources such as food and breeding sites as well as indirectly by altering habitat and modifying hydrology, nutrient cycling and other ecosystem processes. Together these impacts are resulting in the loss of biodiversity and dramatic changes to ecosystems. Apart from their threat to biodiversity and ecosystem services, introduced fishes have a significant environmental, ecological and socio-economic impact. Their introductions mainly cause reduction of yields from fisheries, decrease water clarity and contribute to the spread of disease. Common characteristics of introduced fish species include adaptability (e.g., non-selective diet, variety of environmental conditions), few natural predators or population controls, high reproductive capacity, the ability to thrive in disturbed ecosystems and superior capacity to compete for food and habitat. So, to minimize their impacts, various management strategies must be used such as prevention, early detection and rapid response and eradication through physical, chemical and biological control methods. Different sources reported that not all invasive species have a negative impact instead they serve as food and biological control agents. So, this review paper provides basic information about impacts and management strategies of invasive fish species.

Keywords: Biodiversity, ecosystem function, exotic species, management

Introduction
Alien or exotic aquatic organisms are non-native plants and animals including fishes introduced into new habitats where they do not belong and are worldwide agents of habitat alteration and degradation (Singh and Welfare, 2017) [69]. They are considered as the second threat to biodiversity next to habitat alteration (García-Berthou, 2007) [25]. This is mainly due to predation, competition, hybridization with native species and disruption of ecosystem processes and functions (Walsh *et al*., 2012) [79]. The introduction and spread of non-native species is commonly known as "least reversible" human-induced global change that cause harm to economies (e.g., fisheries and tourism), environment, human health and aesthetics (Ellender and Weyl, 2014) [21]. The impact of exotic species often leads to not only declining populations of native species but also cause local or global extinction directly or indirectly (Butchart, 2008) [12]. Besides being one of the first causes of animal extinctions (Clavero and Garcia, 2005) [18], invasive alien species also severely affect the ecosystem services we depend upon (Vila *et al*., 2010) [76]. Biological invasion has its own economic consequences, for example, in Europe alone, it is estimated that the overall losses due to invasions are above 12 billion euro/year (Kettunen *et al*., 2009) [36]. Furthermore, the number of invasive alien species in Europe is constantly increasing, with a rate of 76% in the 1970-2007 periods (Butchart *et al*., 2010) [13].
Invasive species consists of characteristics such as fast growth, rapid reproduction, high dispersal ability, phenotypic plasticity and ecological competence. They are also able compete to form their suitable habitat based on their preference (Rodriguez, 2006) [61]. Thus habitat-forming invasive species often have widespread effects on entire ecosystems even though, their positive and negative effect on the native is varied (Gribben *et al*., 2013) [29]. Many invasive species prefer upper parts of different habitats (e.g. lakes, wetlands, etc.) to reduce any predation pressure and to make their habitat suitable for colonization (Wonham *et al*., 2005) [84]. Some invasive species also prefer bottom parts of such habitat and various negative impacts resulted on competitors (Thorpe and Callaway, 2011) [73]. Even though the intraspecific effect of habitat-forming invasive species on different community remains

obscure, they have a capacity to simultaneously engineer both above and below-ground factors (Gribben *et al*., 2013) [29]. In Africa, South Africa is one of the severely affected countries by alien invasions in the world (Macdonald *et al.*, 2003) [42]. Alien species are widespread especially in rural areas of the country (at least 161 species cause serious problems in natural systems). Around, 80% of the country or roughly 20milion hectares were affected (Le Maitre *et al*., 2000) [38]. Out of the total 161 species, 117 alien species were well established, major invaders that are more widespread throughout the country (Nel *et al*., 2004) [51]. According to Marais *et al*. (2004) [44] the country would spend 34 billion dollars over the next 25 years to clear 20 million hectares of invasive alien vegetation. Ethiopia is also one of the east African countries that has also a long history of introduction of alien plants and animals whether intentionally or unintentionally (Amare Seifu *et al*., 2016) [6]. Recently, there are about 59 invasive alien species in Ethiopia (GISD, 2005) [26]. Therefore, the main objective of this seminar paper is to assess the impacts of introductions of alien fish species on ecological, environmental and socio-economic aspects and its management strategies.

Invasive fish species

The conservation of freshwater fishes is recognized as an important global issue since the number of species that are extinct, endangered or becoming rare is increasing dramatically as a result of numerous anthropogenic perturbations such as pollution, changes in land use, river management and dam building, the introduction of exotic species, deforestation and effluent discharges (De Silva *et al*., 2007) [19]. However, most native freshwater fish species are highly affected by the introduction of exotic fishes. Fish are among the most commonly introduced and threatened aquatic animals throughout the world (Gozlan *et al*., 2010) [28]. Exotic fishes have been intentionally introduced mainly to enhance fisheries and aquaculture production thus increasing available animal protein sources especially in developing countries (Acosta and Gupta, 2005) [2]. In contrast, fish are most often introduced to support recreational fishery activities in developed countries. Although fish introductions help to achieve their desired economic objectives (Gozlan, 2008) [27], subsequent invasions and the resultant homogenization of biota are deliberate. Biotic homogenization refers to a decrease in taxonomic, genetic and functional differences among previously distinct biota. Such homogenization caused by the introduction of non-native species also causes loss of native species, most of which may be rare, localized and endemic (Sko and Simo, 2012) [70]. Even though, positive and negative impacts of introducing fish species are always debatable (Valéry *et al*., 2013) [74], research on the impacts of non-native fishes is very important for developing solutions to difficult conservation problems (Richardson and Ricciardi, 2013) [59].

Globally, of 1424 freshwater fish introductions, 64% of them have become established (Ruesink, 2005) [62]; 50% of 1205 fish introductions recorded for aquaculture have established in the wild (Casal, 2006) [17]. Of the total established fish populations, approximately 60% are documented as invasive (Simo *et al*., 2009) [68]. All established introduced fish population (64%), produced well-supported ecological impacts on food availability, habitat structure and nutrient dynamic (Ruesink, 2005) [62]. Gozlan (2008) [27] argued that the probability of an ecological impact resulting from freshwater fish introduction is relatively low (around 6%) and presents many positive aspects. However, the idea reported by Gozlan (2008) [27] is unacceptable over the world because the method that was used for the analysis was not clear and oversimplified by considering all FAO areas of the world as internally homogeneous (climate, economy, culture, biological diversity) and equally diverse in freshwater fish (Simo *et al.*, 2009) [68]. For the purpose of aquaculture yield improvement and biological control, fishes are introduced but they are able to alter ecosystem through predation, hybridization, introduction of parasites, competition and alteration of existing food webs (Ogutu-Ohwayo and Hecky, 1991) [52]. For example, common carp is one of fish species introduced throughout different freshwater bodies including Lake Koka Ethiopia to enhance aquaculture production (FAO, 2004) [23]. However, common carp feed on the softest benthic substrates of rivers and lakes and leads to increased siltation, decline of water quality and harming native flora and fauna. This invasive species is also associated with the decline and local disappearance of native fishes in Argentina, Australia, Venezuela, Mexico, Kenya, India etc. (Welcomme, 1988) [80]. Some of the most ecologically disastrous introductions have involved the transfer of predatory fishes (Gozlan, 2008) [27]. Introduced predators may become competitors of the native predators for preferred prey and a predator on smaller-sized native predators and the juveniles of the larger predators (Olowo and Chapman, 1999) [55]. Various invasive fish species are present that have many ecological and socio-economic problems in Africa (Alpert, 2006) [5]. Some of the invasive fish species in Africa include *Carassius auratus*, *Esox lucius*, *Gambusia affinis*, *Gambusia holbrooki*, *Oncorhynchus mykiss*, *Oreochromis aureus*, *Oreochromis niloticus*, *Poecilia reticulata*, *Salmo solar*, *Salvelinus fontinalis*, *Coptodon zilli* and *Tinca tinca* (GISD, 2005) [26]. Some of them are also found in a country commonly known as a water tower of East Africa (Ethiopia). Ethiopia has a number of inland water bodies and its lakes and rivers cover a total area and length of about 7400km^2 and 7700km, respectively (Wood and Talling, 1988) [85]. Relatively a large number of small, medium and some large rivers of Ethiopia have not been well studied. Diversity, distribution and population of ichthyofauna have been poorly known (Abebe Getahun, 2005) [1]. Although ichthyofauna of Ethiopia have been poorly known, some studies classify fish species of Ethiopia as native, invasive and endemic species (Tadlo Awoke and Mebratu Melaku, 2017) [72]. For instance, more than 200 fish species with a mixture of Nilo-Sudanic, east African and endemic forms of fish are found in Ethiopia. From the total of 200 fish species of Ethiopia, 40 and 10 of them are endemic and exotic, respectively (Shibru Tedla and Fisha Haile Meskel, 1981) [65]. Not only fish species but also various introduced plant and animals are found in Ethiopia. For example, GSID (2005) reported that around 59 invasive species (plant and animal) are widely distributed in Ethiopia; out of this some of them are invasive fish species such as *Esox lucius* (common pike), *Gambusia holbrooki* (Mosquitofish), *Oncorhynchus mykiss* (brown trout), *Oreochromis* spp. (Tilapia species) and *Coptodon zillii*. Fish introduction in Ethiopia started during the Italian invasion and then the practice expanded in many natural and man-made waters. Information on management, status and impact on the aquatic environment were not well documented (Mihret Endalew, 2015) [48]. All invasive species may not be successfully established out of their native area. For example, there was unsuccessful effort to introduce Mosquito fish (*Gambusia* sp.) and European Pike (*Esox lucius*) into Lake Tana (Shibru Tedla and Fisha Haile Meskel, 1981) [65].

Most common invasive fish species in the world

Nile perch

In 1950s, the most well-known introduced fish (*Lates niloticus*) species were stocked in the largest tropical lake in the world (Lake Victoria), which is about 68,800km^2. Its introduction was to support the lake's economy by feeding on "trash haplochromines and convert them into more desirable table fish" (Pitcher, 1995) [56]. Over time, severe ecological impacts such as decline of haplochromine species, competition and alteration of food web and food chain in the lake happened (Olowo and Chapman, 1999) [55]. It has contributed to the extinction of more than 200 endemic fish species through predation and competition for food (Kaufman *et al*., 1997) [35]. Then the dramatic increase in Nile perch in the 1980s was followed by a decline in populations of several indigenous species (Kaufman, 1992) [34]. The flesh of Nile perch is also oilier than that of the local fish, so more trees were felled to fuel fires to dry the catch. The subsequent erosion and runoff contributed to increased nutrient levels, opening the lake up to invasions by algae and water hyacinth (*Eichhornia crassipes*). These invasions, in turn, led to oxygen depletion in the lake, which resulted in the death of more fish. Commercial exploitation of the Nile perch has displaced local men and women from their traditional fishing and processing work. The far-reaching impacts of this introduction have been devastating for the environment as well as for communities that depend on the lake (Witte *et al*., 1992) [81].

Common carp

The common carp (*Cyprinus carpio*) is the third species cultivated in aquaculture worldwide. It was introduced in inland waters of 121 countries in the world and established in 91 countries out of 121 countries and recognized as having adverse ecological effects in 15 countries (Casal, 2006) [17]. The common carp was the first fish species carried out of its natural range, by the Chinese (3,000 years ago) and Romans (2,000 years ago). Along with the Nile tilapia (*Oreochromis niloticus*, Cichlidae), the common carp is one of the most widespread introduced species, with high probability of habitat expansion (Zambrano *et al*., 2006) [86]. Carp feed on sediments, fish and plant matter but it doesn't fully digest, excretion promotes algae growth (Cardona *et al.*, 2008) [16]. This species was also introduced to Ethiopia in Lake Koka by a Catholic priest Aba Samuel from Italy in the late 1960s (Elias Dadebo *et al*., 2015) [20]. The species is an omnivorous bottom feeder fish. Since it disturbs the bottom sediment while feeding, it is known to increase water turbidity (Ali *et al*., 2010) [4].

Tilapias

Tilapias mainly Nile tilapia is commonly known as the model for aquaculture (Zambrano *et al*., 2006; Simo *et al*., 2009) [86, 68]. They are extremely widespread and established from North America down to South America (Zambrano *et al*., 2006) [86]. Nevertheless, introduction of the tilapias is still promoted by state agencies throughout different counties (e.g. North America and South America) and they are valued for aquaculture because they are extremely hardy, tolerant, with parental care and extreme feeding flexibility (Freire and Prodocimo, 2007) [24]. The deleterious effect of the Nile tilapia on the native fauna worldwide has been extensively reported. However, Nile tilapia also changes native community structure, reduces abundance of planktonic micro crustaceans, lowers water transparency and increases the abundance of microalgae (Okun *et al*., 2008) [53].

Mozambique tilapia

Oreochromis mossambicus or Mozambique tilapia, is native to the eastward flowing rivers of central and southern Africa (Laxmappa *et al*., 2015) [37]. Because of its tropic flexibility, ability to tolerate extreme environmental conditions rapid reproduction and maternal care of offspring's, it is considered as successful invaders (Laxmappa *et al*., 2015) [37]. This invasive species is also well known by causing environmental and ecological problems in many countries (Canonico *et al.*, 2005) [15]. As a result, *O. mossambicus* is listed in the Global Invasive Species Database (2006) as being in the top 100 invasive alien species on the planet (Laxmappa *et al*., 2015) [37].

North African catfish

African catfish (*Clarias gariepinus)* is widely distributed in Africa and its main habitats are calm lakes, rivers and swamps in areas that flood on a seasonal basis. *C. gariepinus* has pseudo-lungs, long bodies and a high capacity to produce mucous as adaptations to live in stagnant environments or out of water. In its natural range it is reported as omnivorous; feeding on plant material, plankton, arthropods, mollusks, fish, reptiles and amphibians (Vitule *et al*., 2006) [77]. During the 1990s, *C. gariepinus* started to be cultivated in fish farms throughout Europe, Asia and Latin America including Brazil (Verreth *et al*., 1993) [75]. However, catfish was not supported by the local market instead used in sport fish pond (in Brazil named as pes-que-pague='fish-and-pay'). There was no protective apparatus of the pond to prevent escape of the species, resulting in the invasion of this species in rivers and lakes (Vitule *et al*., 2006) [77]. The same problem with African catfish and its hybrids have been reported in South Africa. Although both catfish and channel catfish have known ecological and environmental problems, both of them play a key role to increase production significantly (Simo *et al*., 2009) [68].

Walking catfish (Clarias batrachus)

Clarias batrachus is one of the most notable catfishes in Asia (Argungu *et al*., 2012) [7] and its popularity has increased significantly as an important commercial aquaculture species. *C. batrachus* was introduced into Florida, USA from Thailand and was accidentally released into the aquatic environment from the Penagra Aquariums, during the mid-1960s (Argungu *et al*., 2017) [8]. In the 1970s, this exotic catfish species expanded to more than 25% of the freshwater area of Florida and threat to native fish species due to its voracious and opportunistic feeding habits, high fecundity and its ability to migrate on land.

Lionfishes

Lionfishes (*Pterois volitans* and *Pterois miles*) are one of the most severe marine finfish invasions with the potential to devastate the fragile economic sectors existing in the Caribbean (Morris *et al*., 2008). The potential economic loss of marine biodiversity due to the introduction of this species is about US$11,187,937 (Campus and Bay, 2011) [14].

Invasive lionfish have substantial negative impacts on Atlantic coral reefs and it also caused significant reductions in the recruitment of native fishes by an average of 79% over the 5-week duration and effects on a key life stage of coral-reef fishes (Albins and Hixon, 2008) [3].

Mosquito fish

Fishes are stocked in natural water bodies not only for productions but also to biologically control mosquito populations by stocking the mosquitofish (*Gambusia affinis)*. However, introduced biological control agents may have harmful ecological impacts (Simberloff and Stiling, 1996) [66]. Mosquito fish is a small, harmless-looking fish native to the fresh waters of the eastern and southern United States. It has become a pest in many waterways around the world following initial introductions early last century. Different studies suggested that *Gambusia* (small Poeciliidae) fish is far from a remedy to control mosquito due presumably to their generalist feeding habits, they are not always effective to reduce mosquitoes. They have own negative impact on non-target organisms including amphibians, the eggs of economically desirable fish and preys on and endangers rare indigenous fish and invertebrates. The commonly known larvae affected by *Gambusia* is *Salamandra* larvae (Segev *et al*., 2009) [63]. Mosquito fish are difficult to eliminate once established, so the best way to reduce their effects is to control their further spread. One of the main avenues of spread is continued, intentional release by mosquito-control agencies (GISD, 2005) [26].

Brown and Rainbow trout

Brown trout (*Salmo trutta*, Linnaeus) and Rainbow trout (*Oncorhynchus mykiss*, Walbaum) have been introduced intentionally for recreational and commercial fishing throughout the world (Elliott, 1994) [22]. In Ethiopia, both Brown and Rainbow trout are introduced in the early 1970s, from Kenya to the rivers of Bale National Park. The same is true in New Zealand, these two species were introduced in the late 1880s and now they are top predators in many water bodies of the country. Their impact includes alteration of invertebrate behavior, fragmentation of native fish populations, altered community composition and top-down effects on ecosystem structure and function (Burrill, 2014) [11].

Largemouth bass

The largemouth bass (*Micropterus salmoides*) is a piscivorous fish from North America that has been introduced to more than 50 countries (Welcomme, 1988) [80] and able to change the food-web structure (Jackson, 2002) [32]. The species was introduced to Japan in 1925 for the purpose of sport fishing and aquaculture and had spread across many Japanese lakes and ponds. Degradation of species richness of fauna and extinction of local fish populations in Japanese lakes and ponds following invasions of largemouth bass (Hiroshi and Yoshito, 2012) [31].

Northern snakehead

Snakeheads (*Channa* spp. and *Parachanna* spp.) are native to parts of Asia and Africa which invade U.S. waters by way of aquarium release. Northern snakehead poses the greatest threat in the United States because of their aggressive piscivores, growth rate and tolerance to low temperatures (Herborg, 2007) [30]. This species wiped out native forage populations and displace sport fishes that contribute millions of dollars to local economies (Love and Newhard, 2012) [41].

Importance of introducing fishes

Aquaculture

Aquaculture is the rapidly growing sectors of the world (Biswas, 2014) [10]. Among numerous reasons for introduction of exotic aquatic animals into countries, aquaculture development is said to be a main motive (Welcomme, 1988) [80]. Fish farmers are trying to have more production of fish to earn more profit by introducing different kinds of exotic fishes (Singh and Welfare, 2017) [69]. They have always comprised a significant proportion of the total but have grown in importance in recent times especially in the last few decades. The main reason behind this is, probably, due to the demand for a particular species and trade in the global market. Exotic species have played an important and significant role in the development of aquaculture and trade in aquaculture products. As a result of this trend, only nine species accounted for 78% of the total world freshwater fish culture in 1996 (Singh and Welfare, 2017) [69]. These major species for fish culture have been introduced into countries throughout the world. For example, the most well-known introduced species in inland water ecosystem is common carp (*Cyprinus carpio*), which helps to enhance aquaculture production over 3.2 million tons (over 95% in developing counties) in 2002 (FAO, 2004) [23].

Management of Inland Waters

The second importance of introduction is that aiming at the manipulation of wild or modified stocks in natural water bodies. Stocks of this kind are used for sports or recreational fishing and for a variety of food fish ranging from subsistence to commercial. Sportfishing has provided the second major motive for introduction with a relatively constant number of introductions per decade, although introductions for this purpose have relatively declined in importance since the 1950s. All over the world as of 1988, seventy- eight species were recorded as having been introduced for sport purposes. A great number of these are salmonids or larger predators having the fighting qualities sought by sport fishermen. In India too, salmonids were introduced in the high altitudes for the development sport fisheries (Singh and Welfare, 2017) [69]. Brown trout (*Salmo trutta*, Linnaeus) and Rainbow trout (*Oncorhynchus mykiss*, Walbaum) have been introduced intentionally for recreational and commercial fishing throughout the world (Elliott, 1994; May, 2007) [22, 45]. In Ethiopia, both Brown and Rainbow trout were introduced in the early 1970s from Kenya to the rivers of the Bale National Park for the sake of recreational (sport) fishing. These fishes have attracted many tourists and have contributed to earn a considerable foreign exchange. To catch trout fish, a tourist gets permission from the near-by Agricultural office or from the Ministry of Agriculture after paying fees in advance before fishing. The fishing license given to the tourist may be on daily basis, weekly, monthly or annually depending on their request. The number of fish to catch per day per hook is limited up to five fish only and not allowed for commercial purpose (Selamu Abrham and Lelise Mitiku, 2018) [64].

Improvement of Wild Stocks

The motives for introduction of fish species to improve wild stocks are numerous, which includes establishment of new food fishes, filling vacant niches, stocking natural waters, providing forage for predators, restoration of fisheries, establishment of a wild stock, control of stunted species etc. An example of such successful introduction is one when herbivorous fish such as grass carp or common carp are introduced to convert primary production into meat by utilizing the macrophytic or phytoplanktonic organisms. Silver carp (*Hypophthalmichthys molitrix)* is also introduced to curb excessive growth of blooms. This kind of fish associations refers to polyculture of fish farming practices which can be extended to management of small water bodies and for extensive fish culture (Singh and Welfare, 2017) [69]. About six exotic species such as *Lates niloticus, Cyprinus carpio, Coptodon zillii, Oreochromis niloticus, O. leucostictus* and *O. melanopleura* are introduced into Lake Victoria for different purposes (Okemwa and Ogari, 1994) [54]. For example, *L. niloticus* (Nile perch) was introduced into Lake Victoria by officials of the Uganda Game and Fisheries department between 1954 and 1957 (Reynolds *et al*., 1995) [57]. Its introduction was mainly for sport fish and to feed on the smaller sized haplochromine cichlids that were at that time abundant but of lesser economic value, so as to convert their biomass into larger table sized fish (Reynolds *et al*., 1995) [57]. The introduction of the tilapias species in Lake Victoria such as *Coptodonv zillii* was to fill an apparently vacant niche of a macrophytophage, whereas *O. niloticus* and *O. leucostictus* were introduced to supplement stocks of the native tilapias and *O. melanopleura* was introduced accidentally from fishponds (Okemwa and Ogari, 1994) [54].

Ornamental Purpose

In view of the global demand on colorful fishes and increase in aquarium trade for keeping aquarium in homes and working places, alien fish species have been introduced worldwide (Singh and Welfare, 2017) [69]. Several species were introduced for stocking into natural waters or ornamental ponds: the main species used for this purpose is the goldfish, *Carassius auratus,* which has been widely distributed outside its natural range and which has frequently escaped into the wild. On the other hand, innumerable species of small, mostly tropical fish have been widely dispersed by the flourishing aquarium trade (Singh and Welfare, 2017) [69].

Biological Control

As early as in 1920s attempts were made by introducing exotic fish species to eradicate mosquito larvae as a measure for controlling malaria (Singh and Welfare, 2017) [69]. Twelve species have been introduced for mosquito control, but most extensive introductions were made with 3 species such as *Poecilia latipinna, Poecilia reticulata* and *Gambusia affinis*. Control of mosquito larvae by these small larvivorous fish species was very effective and is replacing the more costly and environmentally harmful control with insecticides. The introduced *Gambusia* sp. is now gradually being replaced by native larvivorous species (Singh and Welfare, 2017) [69].

Impacts of introduced fish species

Ecological Impacts

The factors that determine the ecological impacts of invasive alien species are the invading species, extent of the invasion and vulnerability of the ecosystem being invaded (Levine, 2000) [39]. Loss and degradation of biodiversity due to invasive alien species can also occur throughout all levels of biological organization from genetic to population, species and community level. Invasive alien species generally reduce the abundance of native inland water species through predation, hybridization, parasitism or competition for resources (Olowo and Chapman, 1999) [55]. For example, out the total 24 species or subspecies of fish believed to have gone extinct despite listing under the U.S. Endangered Species Act, three of them are due to hybridization with introduced species *Cyprinodon nevadensis* (Cyprinidae), *Gambusia amistadensis* (Poeciliidae), and *Coregonus alpenae* (Salmonidae) (McMillan and Wilcove, 1994) [46]. Kudhongania *et al*. (1995) noted that hybridization leads to the restructuring of the tilapia communities in Lake Victoria. Hybrids between *O. niloticus* and *O. variabilis* and between *Coptodon zillii* and *O. melanopleura* were identified in Lake Victoria with apparent dominance of *O. niloticus* in the crosses. Fishes introduced for biological control have disastrous impacts on native fishes and other species. For example, *Gambusia affinis* and *G. holbrooki* have been spread throughout the world for mosquito control but also prey on frogs, invertebrates, and other fish, often with devastating consequences (Mieiro *et al*., 2002) [47].

When invasive alien species are successfully established, interactions between them and native species during reproduction can result in severe impacts on native species. Erosion of native gene pools can occur directly through hybridization, competition, potentially resulting in sterile offspring and an associated decrease in population size. The most extreme genetic effect is hybridization. Many fish species regularly hybridize with closely related species and frequently with those of greater geographic and taxonomic divergence. Hybrids may be self-fertile and will breed true in which case an essentially new species is created such as the various red tilapia, self-fertile strains can eventually revert to their parental forms through backcrossing, not self-fertile but capable of producing viable offspring with one or both of the parental species and sterile. Hybridization among species in the natural environment can pose risks because valuable adaptive characteristics, such as timing of migration and the ability to locate natal streams may be lost in the host species. Alternatively, the hybrid can prove more successful and vigorous than the parents, in which case they may disappear through competition. The most obvious examples of the consequences of genetic interactions are hybridization events followed by erosion of the gene pool of native species, such as hybridization between invasive alien rainbow trout (*Oncorhynchus mykiss)* and native trout populations (cutthroat trout, *Oncorhynchus clarki*) between invasive alien mallard ducks (*Anas platyrhynchos*) and the New Zealand gray duck (*Anas superciliosa superciliosa*), the Hawaiian duck (*Anas wyvilliana*) and the Florida mottled duck (*Anas fulvigula fulvigula*). As a result, the populations of both native trout and New Zealand gray duck have declined dramatically (Simberloff and Stilling, 1996) [67].

Environmental impact

Environmental impacts of non-native species include loss of native biodiversity due to preying upon native species, decreased habitat availability for native species, competition, hybridization etc., changes to ecosystem function and changes in nutrient cycles and decreased water quality. Introduced species can disturb habitats and in so doing, alter ecosystem characteristics to such a degree that native species are threatened. A notable example of such behavior is the common carp, which digs for food in the muddy bottoms of lakes and rivers, stirring up sediment and biological oxygen demand (BOD). This can lead to turbid conditions that reduce light penetration and plankton production. Another form of behavior is burrowing. Many introduced crayfish varieties can seriously damage pond banks and river levees. In comparison with direct effects of predation and competition, the effects on environment by naturalized introduction of fishes are comparatively lesser. The consequences can have impacts on several trophic levels. Aquatic food webs are very complex, particularly in tropical areas. Some attempts were made to modernize their functioning, in order to be able to predict consequences of an exotic fish introduction on environment. The best known effect is on the cascading effect on trophic levels, which postulates that the biomass of a population is the result of equilibrium between available trophic resources (bottom-up control) and predation exerted (top-down control) (Singh and Welfare, 2017) [69]. The consideration of a classical food chain is rise in piscivorous biomass results in decreased fish. The opposite may also happen as an increase in planktonic algae might influence carnivorous species through the trophic cascading interactions. This theory has given good results when applied to North American and some European lakes. It allowed linking several trophic levels and as a consequence, sustained the idea of introducing predatory fishes to fight eutrophication of lakes. This management is therefore called bio-manipulation and it consists of introducing a predatory fish. Bio-manipulation is a technique used to restore eutrophied lakes (Riedel-lehrke, 1994) [60]. Based on the consideration of cascading trophic interaction it is possible to reduce phytoplankton abundance through the elimination of fish feeding on zooplanktivorous in order to allow the increase of phytoplankton grazing by herbivore zooplankton. Bio-manipulation is also being used to manage the aquatic food web in order to improve the fishery production. The consequence of the introduction of *Lates niloticus* into Lake Victoria resulted in crash of the native cichlid populations feeding on invertebrates, which raised the population of some insects (Welcomme, 1988) [80].

Alteration of habitat

The introduction of exotic aquatic organisms may have a negative impact on the habitat of native species. The consumption of plant material by herbivorous fishes, the uprooting of macrophytes through digging for food or for nesting sites and the organic enrichment which increases turbidity and thus reduces light penetration and photosynthesis all of which can result in displacement of aquatic vegetation. The common carp, *Cyprinus carpio*, through its habit of rooting around in the bottom, has the reputation of muddying the waters. This shades out macrophytes, disturbs benthic invertebrates and through the more rapid recycling of phosphate contributes to accelerated eutrophication. In India, the composition and abundance of the native fish fauna is altered, where species of the genus *Schizothorax* have disappeared from waters to which carp had been introduced, together with the fisheries based on them. *Ctenopharyngodon idella* has been introduced into many areas of the world with the intention of eliminating submerged and emergent vegetation. It usually performs this task adequately but, through selective feeding on more tender species, which may favour the development of tougher vegetation, which is even more of a nuisance (Singh and Welfare, 2017) [69].

Socio-Economic Impacts

Invasive fish species have not only negative impact on the ecosystem but also on the local economies. There socio-economic impacts fall into two broad categories: market impacts and non-market impacts. Market impacts imply changes in productivity of commodities sold within the marketplace. For inland water ecosystems affected by invasive alien species, these production changes which include losses can involve decreases in fisheries and aquaculture production, decreases in the availability and accessibility of clean water and declines in property values. Non-market negative impacts due to invasive alien species in inland waters can include potential risks to human capital due to premature deaths, declines in social capital due to increased transaction costs and declines in natural capital due to the loss of ecosystem services (May, 2007) [45]. For instance, Sea lamprey (*Petromyzon marinus*) caused significant economic and commercial losses to Great Lakes fisheries in the U.S.A. and Canada. It has been estimated that if sea lamprey was not controlled, the loss of fishing opportunities and indirect economic impacts could be greater than $500 million annually. The salmon parasite, *Gyrodactylus salaris,* came to Norway with imported salmon smolt and rainbow trout (*Oncorhynchus mykiss*) fingerlings from Sweden in 1975. *Gyrodactylus* now causes annual losses in the order of NOK 200–250 million in Norwegian river systems (May, 2007) [45].

Strategies to minimize impacts of invasive alien fish species

Biological invasions are increasing in frequency and the need to mitigate or control their effects is a major challenge to natural resource managers. Failure to control invasive species has been attributed to inadequate policies, resources or scientific knowledge. Often, natural resource managers with limited funds are tasked with the development of an invasive species control program without access to key decision-support information such as whether or not an invasive species will cause damage and what the extent of that damage may be. Once damages are realized, knowing where to allocate resources and target control efforts is not straightforward (Wittmann *et al*., 2015) [82]. Successfully managing invasive species includes prevention, eradication, and control.

Prevention

Prevention of the introduction of invasive alien species is the most obvious first and most cost-effective measure against invasive alien species because once an introduced species has become established it can be extremely difficult or more often impossible to eradicate. Intact ecosystems are the best preventative measure against invasive alien species; as such species often thrive in disturbed ecosystems. Preventing new invasions requires creative approaches to education and outreach, screening and injurious wildlife prohibitions and rapid response techniques. Building political will for implementation of preventative measures is a significant challenge, particularly when the negative impacts have not yet occurred or there is a conflict of interest between parties that desire the invasive alien species introduction and those who oppose it. Had the Zebra Mussel (*Dreissena polymorpha*) been prevented from entering North America by purging of ballast water at sea or by treatment of ballast water by chemicals or ultraviolet light, extinction threats to numerous freshwater species would be far lower than they currently are (Ricciardi *et al*., 1998) [58]. In addition, billions of dollars of industrial damage from clogged water pipes would have been avoided. However, the threats posed by ballast water discharge have been known for a long time before the damage occurred.

Early detection and rapid response

The term rapid response refers to the steps taken upon the detection of a non-indigenous species and encompasses a range of possible actions ranging from eradication, management of population abundance or dispersal to a decision against an active response (Locke *et al*., 2009) [40]. It is the capacity to quickly respond to detection of colonization by a non-indigenous species. The primary goal of most rapid response plans is eradication of the non-indigenous species or reduction of its population below levels needed for reproductive success (Myers *et al*., 2000) [50]. However, eradication is not always an attainable or affordable goal. In decreasing order of desirability, the goal of the rapid response may entail eradication, containing the problem to a given area, suppressing the population to slow its spread, developing management strategies to keep the species at an abundance which is below and economic or ecological threshold or learning to live with the problems caused by the species (Myers *et al*., 2000) [50].

Eradication, control and management

Eradication refers to all efforts aimed at completely eliminating an invasive species from a given system; control refers to all efforts aimed at maintaining an invasive species population under a predetermined size value within a given system and management refers to all actions and efforts related to the eradication, control and containment of an AIS as well as to actions related to the prevention of new introductions and re-introductions (Wittemberg and Cock, 2005) [83]. Following the introduction of an exotic species, there is an opportunity to eradicate it through a rapid response action if detected in time. If the invasion has spread to a point that eradication is not possible, then the species may be subject to control and management efforts. Regardless of whether the goal is eradication or control/ management, there are different options to consider. These include mechanical/physical, chemical and biological control methods. These methods can be used alone or in combination in order to increase efficiency. Integrating pest management strategies allow managers to tie different control options to different areas, times and life-history stages in an effort to minimize risks and costs while maximizing prospects for control success and protection from reinvasion. Unambiguously, valuable methods to control invasive fish must be effective, against the AIS targeted while inflicting acceptable level of harm to non-target organisms (i.e. be selective), be safe, affordable and easy to apply or implement, stop acting within a reasonable limit of time (i.e. not be persistent), be effective over a broad range of environmental conditions, be registered for use in the aquatic environment and be acceptable according to stakeholders' perception.

Mechanical/physical control

Mechanical control involves directly removing individuals of the invasive alien species either by hand or using machinery (i.e., fishing, pulling weeds) or draining of the water body that has become infested. It is highly specific to an invasive alien species and is often very labour intensive. Some examples of mechanical control include dewatering, netting and trapping, electrofishing etc. Dewatering means the drainage of water bodies as a strategy to kill undesirable fish populations is a practice that is advantageous because it represents low risks to human health and usually inflicts limited long-term effects on the ecosystem. Also, it entails relative uncomplicated permitting process and neutral to positive public perception. On the other hand, dewatering is a nonselective practice, frequently expensive and difficult to implement. This method consists of partial or total removal of water through the construction of drainage ditches or use of pumps. These techniques can be very costly and present various difficulties depending on the characteristics of the site and of the target species. Nets and traps have been employed with various levels of success and in a variety of different settings to control and eradicate non-native fish. Benefits of these physical removal methods include low impact on human health and general neutral to positive public acceptance. Also, the use of nets and traps usually do not impose long-term effects on the ecosystem. However, these approaches tend to be ineffective and cost-prohibitive in larger water bodies especially in the capture of the full range of sizes in a population. For instance, a mesh size appropriate for capturing adults may allow juveniles to escape, while using a smaller mesh size may be inefficient to capture larger individuals (gill nets) or yet clog the nets in a way that it becomes very difficult to haul them in. Selectivity of nets and traps will vary with fish size and behavior but these methods are usually indiscriminate in nature and can also result in damage to valued species of fish. These negative impacts can be minimized by returning valued fish to the water but this mitigation practice adds extra cost to an already expensive method. For example, tilapia species are known to be especially hard to catch with nets especially under invasive conditions (Joana, 2009) [33]. According to experts in aquaculture, when culture in ponds, tilapia are best harvested by seining and draining the pond. A complete harvest is not possible by seining alone. Tilapias are adept at escaping a seine by jumping over or burrowing under it. Only 25 to 40% of an *Oreochromis niloticus* population can be captured per seine haul in small ponds. Other tilapia species such as *T. aurea* are even more difficult to capture. A l-inch mesh seine (with bag) of proper length and width is suitable for harvest. Electrofishing consists of using electric fields in water to stun fish and by doing so, to facilitate their capture. This method is commonly applied for surveying purposes to sample fish populations and determine abundance, density and species composition. Electrofishing normally does not kill fish which apparently return to their natural state shortly after being stunned, mortality can occur and recent evidence indicates that the practice can cause substantial injury to the spinal column and associated tissues of fish that survived pulsed direct current. Electrical-field factors considered in the literature to affect the incidence of electrofishing-induced mortality and spinal injuries (including associated hemorrhages) include type of current, intensity, duration, orientation (relative to the fish) and for AC and PDC, waveform characteristic such as pulse or wave frequency, shape and width. Related biological factors of concern include species, size and condition (Snyder, 2003) [71]. Electrofishing as a management and control tool and has some important limitations. It is intensive and requires ongoing application to be effective, expensive to implement and involves the use of specialized gear and trained staff, unlikely to lead to total eradication, as some fish will always evade capture and only likely to be effective in small, contained systems such as weirs and farm dams.

Chemical control

Chemical control involves the application of chemicals (pesticides or defoliants). It is very effective as a short-term solution and sometimes the only actually capable of achieving the expected control goals (Madsen, 2006) [43]. However, it is important to mind that in every instance in which toxicants or pesticides are used as a management tool, the ecology of the treated system is inevitably disrupted. Potential negative impacts of the use of chemicals include direct and indirect harm to non-target species (including human being), the development of pest resistance to pesticides and secondary pest outbreaks. Depending on the chemical nature and formulation of the pesticide and on the conditions and properties of the application site and application methods, the active ingredient may be transported in the environment through particle drift, evaporation, leaching or yet by residues on treated species. In addition, certain pesticides have the potential to persist in the environment for extended periods of time and may cause the contamination of adjacent soil, groundwater, superficial water and air leading to indirect harm to non-target species. Other indirect negative effects of chemicals (e.g. pesticides) include the bioaccumulation of the active ingredient in the food chain or the intoxication of non-target species by the solvents used in end-product. Chemical treatment with rotenone has been identified as the most promising alternative to control tilapia in the Kawaiele (Joana, 2009) [33]. This is the only method available at this time that could kill most of the invasive fish populations, with low or no significant side effects, provided that the risk of contamination of groundwater and adjacent aquatic systems is proven to be minimal.

Biological control

Bio-control or biological control refers to the introduction or enhancement of a population of organisms that are predators, competitors, parasites or pathogens of a target species such as unwanted invasive fish. The use of living organisms to control pests is an ancient practice which can in certain instances be beneficial. In general, bio control practices present low risks to human health, can be inexpensive, permanent, self-sustaining and tend to be well accepted by the general public (Bax *et al*., 2001) [9]. There are three general approaches to bio control such as the introduction of a non- native bio control agent, the improvement of existing natural enemies through mass production and periodic release of natural predators, competitors, parasites or pathogens of the pest and ecosystem enhancement, which involves manipulating factors that may limit the effectiveness of natural controlling agents, such as nutrients or third species.

The difficulties associated with developing an efficient biocontrol program are many and usually derive from the still limited understanding of species adaptation, niche plasticity and functional variability in biological communities. Frequent problems of biocontrol programs are related to long-term impacts of bio control agents on non-target species and/ or on natural resources such as food and space. For instance, it is common that a species introduced to compete with or prey on a pest will find an alternative niche and manage to coexist with the pest. Instead, they may displace the target pest but also other beneficial species and by doing so become a pest as well. There are various cases of biocontrol efforts gone wrong in Hawai'i. In fact, target species is a good example of organism that, along with *Gambusia* spp., has been introduced to natural water bodies for the purpose of controlling mosquitoes, a practice that has been proved to be overall inefficient (Bax *et al*. 2001) [9].

Conclusions and Recommendations

- Many introduced fish species have negative impact on native species through predation, competition for the same resource, parasites and disease. So, to minimize such negative impacts, different management strategies should be done.
- Prevention, early detection and rapid response and eradication are the most common management strategies of introduced species.
- An integrated river basin management approach to the prevention and control of invasive alien species should be implemented.
- Involvement of local and indigenous communities and other relevant stakeholders should be promoted at all levels for the identification, prevention and control of invasive alien species in inland water ecosystems.

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