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Research Application Summary

Ecological impacts of common carp and the African sharptooth catfish: A review

Chirwa, E.R.,[1]* Jere, W.,[1] Mtethiwa, A.[1] & Sikawa, D.[1]
[1]Department of Aquaculture and Fisheries Science, Lilongwe University of Agriculture and Natural Resources (LUANAR), P.O. Box 219, Lilongwe, Malawi.
***Corresponding author:** erchirwa@gmail.com

Abstract

Common carp (*Cyprinus carpio*) and the African catfish (*Clarias gariepinus*) have been introduced worldwide for aquaculture. In their novel areas, ecological impacts, arising from their benthivorous and predatory feeding behaviour, have been reported for each separately. Based on these, conflicting regulatory frameworks have been devised in some countries to control their spread in order to preserve native biodiversity. Anecdotal field observations in Malawi suggest that these fishes might impose similar ecological impacts. This paper reviews literature on ecological impacts of common carp (*Cyprinus carpio*) and the African catfish (*Clarias gariepinus*) with a view to (1) identify the ecological impacts reported for these benthivorous fishes, (2) expose ecological impacts that appear common between these fishes, and (3) suggest potential areas of practical research to compare the ecological impacts of these benthivorous fishes.

Key words: Aquaculture, benthivorous, ecological impacts, introduced fish, invasive species

Résumé

La carpe commune (*Cyprinus carpio*) et le poisson-chat africain (*Clarias gariepinus*) sont des espèces introduites pour l'aquaculture de par le monde entier. Dans leurs nouveaux environnements, les impacts écologiques découlant de leur comportement alimentaire de benthivores et prédateurs, ont été reconnus respectivement pour chacune de ses espèces. Sur cette base, des cadres réglementaires contradictoires ont été mis au point dans certains pays pour contrôler leur propagation afin de préserver leur biodiversité d'origine. Au Mali, des observations isolées sur le terrain suggèrent que ces poissons pourraient avoir des impacts écologiques similaires. Ce document passe en revue la littérature sur les impacts écologiques de la carpe commune (*Cyprinus carpio*) et le poisson-chat africain (*Clarias gariepinus*) en vue de (1) identifier les impacts écologiques déclarés pour ces poissons benthivores, (2) exposer les impacts écologiques qui apparaissent communs entre ces poissons, et (3) suggèrer des domaines potentiels de recherche pratique pour comparer les impacts écologiques de ces poissons benthivores.

Mots clés: Aquaculture, benthivores, impacts écologiques, poissons introduits, espèces envahissantes

Introduction

Global demand for fish is increasing due to rise in human population. In many parts of the world, capture fisheries have reached their full potential, and are alone unable to meet the demand for fish. The role of aquaculture in augmenting fish supply is globally acknowledged, and this farming has become the world's fastest growing animal production sector. Common carp, indigenous in much of Asia and Europe, has become the world's most introduced fish species (Zhou *et al*., 2003; ISSG, 2000), contributing about 14% to global aquaculture production (FAO, 2007; FAO, 2015).

Carp has a number of advantages as an aquaculture species, and for this it is considered the number one aquaculture species. It is a fast growing fish, reaches large market size, breeds successfully in ponds, is tolerant to most environmental conditions and easy to handle, can be stocked and raised at higher density and give more profit (Horvath *et al*., 2002).

In spite of the advantages that common carp has as an aquaculture species, the fish is reported to cause negative ecological impacts, making some countries resist its introduction. For example in Malawi, common carp is non-native and prohibited in the Lake Malawi ecosystem for fear that the fish would negatively affect the lake's unique fish biodiversity (Bandula, 1997; Msiska and Costa-Pierce, 1993; Vanden Bossche *et al*., 1990). Its farming is therefore restricted to areas outside the lake's catchment. Consequently the contribution of common carp to aquaculture production in Malawi is low, estimated at less than 2%.

The African catfish (*Clarias gariepinus*), native in much of Africa and Asia Minor, is also introduced for aquaculture in different parts of the world (Khan and Pannikar, 2009; Eagle and Valderrama, 2001; Bruton, 1979a). In Malawi, including the Lake Malawi catchment and much of Africa, this fish is native and widely used for aquaculture. Although its advantages as an aquaculture species may not match those of common carp, the African catfish has gained widespread popularity for its fast growth and commercial viability under intensive culture. Like common carp, the African catfish has met resistance in some countries where it is non-native because the fish is reported to cause negative environmental impacts (Baher *et al*., 2015; Kadye, 2011). For example, some countries in Asia prohibit the use of the African catfish in aquaculture to protect their aquatic ecosystems and native biodiversity (Krishnakumar *et al*., 2011). Common carp, being native, is allowed in these countries.

The fact that the two fishes are unreservedly accepted in their native localities and prohibited in some of their non-native areas due to ecological concerns raises three fundamental questions. What exactly are the ecological concerns for which the two fishes are prohibited in some of their non-native areas? Are the ecological impacts cited for these fishes different? What practical research can be suggested to compare the ecological impacts of these benthivores? These questions not only form the basis of this literature review but also lie at the centre of the need to review policies that prohibit the use of one of the two fishes where the other already naturally occurs. A study to compare the ecological impacts of these benthivores is necessary. Very few studies have compared the effects of two benthivorous fishes on some aspect of aquatic ecosystems. Known examples include Matsuzaki *et al.* (2008) who compared common carp and crayfish impacts, and Milstein *et al*. (2002) and Wahab *et al.* (2002) who compared the impacts of common carp and mrigal (*Cirrhinus mrigala*) on peripyton and fish production in a polyculture system.

Methods of Investigation

Relevant literature on ecological impacts of *Cyprinus carpio* and *Clarias gariepinus* was identified by searching the ISC (Invasive Species Compendium), CABI (Centre for Agriculture and Biosciences International), ASFA (Aquatic Sciences and Fisheries Abstracts) database, Nonindigenous Aquatic Species Database of the U.S. Geological Survey, as well as internet resources such as Scopus and Google Scholar for primary research publications from 1985 to 2015. The search terms were kept as broad as possible to increase chances of capturing all the relevant research material on the topic. These included such terms as "ecological impacts of common carp", and "ecological impacts of African catfish", and "ecological effects of common carp", and "ecological effects of African catfish," and "ecological influences of common carp, " and "ecological influences of African catfish," and "invasive species". Studies were considered appropriate for this review if: (1) they were reported in English language, (2) the objective of the study was ecological effects/impacts/influences of either common carp or African catfish, and (3) at least one ecological impact was reported for either common carp or African catfish. We do acknowledge that although the literature search endeavoured to be comprehensive, it was not exhaustive. However, it has allowed us to establish a comprehensive overview of the most important available literature on the ecological impacts of *Cyprinus carpio* and *Clarias gariepinus.*

The Concept of Ecological harm and invasive species

The Invasive Species Advisory Committee (ISAC) of the United States uses the term "ecological harm" to mean biologically significant decreases in native species populations, alterations to plant and animal communities or to ecological processes that native species and other desirable plants and animals and humans depend on for survival (ISAC, 2006). These effects may be caused by the direct or indirect impacts of invasive species. Are *Cyprinus carpio* and *Clarias gariepinus* invasive species? If they're not, would anyone be concerned about whether or not they're present in a particular environment? The National Invasive Species Management Plan (NISMP) of the U.S. defines the term invasive species as "a species that is non-native to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm or harm to human health." *Clarias gariepinus* possesses certain attributes that predispose it to becoming a powerful invasive fish (Table 1).

The fish is highly fecund[1] , flexible in phenotype, rapid growing, has wide habitat preferences, tolerant of wide range of water conditions, is able to thrive on a great variety of prey and able to hybridize with conspecifics (Bruton, 1986). These characteristics enable the fish to destabilize native fish and aquatic invertebrate species, and are the reason why some countries in Asia such as India prohibit its use in aquaculture (Dhawan and Kaur, 2001).

Similarly, the common carp is considered to be among the world's invasive species due to its high fecundity[2] , ability to cause habitat alterations, diverse and flexible diets depending on what is available, and its ability to feed on eggs and larvae of other fish (RWMWD, 2006). However, the concept of invasive species is not just a biological trait. It is largely an artefact of human values and perceptions. For a non-native organism to be considered an invasive species in the policy context, the negative effects that the organism causes or is likely to cause are deemed to outweigh any beneficial effects (ISAC, 2006). Thus, "many alien species are non-invasive and support human livelihoods or a preferred quality of life." Examples abound in crops and livestock farming.

Table 1. A summary of the invasive characteristics of *Cyprinus carpio* and *Clarias gariepinus* and References where they are cited

Characteristics	*Cyprinus carpio*	*Clarias gariepinus*
1. High fecundity, prolific breeders	Sivakumaran, *et al.*, 2003	Brutton, 1979b
2. Fast growth rate & grow to large size [3]	FAO, 2004-2016; Bruton and Allanson 1980	De Moor and Bruton, 1988
3. Ability to utilize and tolerate a wide range of habitats for spawning, feeding and nursery purposes	Ali *et al.*, 2010	De Moor & Bruton, 1988
4. Flexible phenotype/phenotypic plasticity[4]	Gas and Noailliac-Depeyre, 1976	Bruton, 1986
5. Wide dietary preferences (omnivorous, flexible and opportunistic feeding)	Mustafizur *et al.*, 2010	Bruton, 1986
6. Has potential to hybridize with some native conspecifics, leading to genetic introgression and replacement of natives.	Tang and Chen, 2012; Hulata, G., 1995	Senanan *et al.*, 2004; Poompuang and Na-Nakorn, 2004
7. Multiple sensory capabilities (i.e. use sight in clear waters, and switch to using smell and sensory organs in turbid waters	Weber and Brown, 2011	De Moor, 1988; Bruton, 1977
8. Aggressively compete with native fauna for food and spawning space, largely out-competing native species	Weber and Brown, 2011	De Moor, 1988; Bruton, 1977

[1]A 6 kg female catfish can produce between 150, 000-300, 000 eggs (Brutton, 1979b).

[2]Carp mature as early as1 year for males and 2 years for females, and a 6 kg female can lay a large numbers of sticky eggs (up to 1.5 million) (Sivakumaran, *et al.,* 2003)

[3]Carp can grow by 2 to 4 percent of body weight daily, and can reach 15 kgs in 4-6 years. Catfish can grow to 20 cm and mature within 12 months and can reach 60 kgs in weight or 170 cm in length (Skelton 2001; IGFA 2001; Robbins *et al.* 1991)

[4] Phenotypic plasticity in this paper refers to the ability of an organism to produce different phenotypes (e.g. morphological, physiological, biochemical, behavioral, life-history) in response to a change in external and/or internal environmental conditions (Piersma *et al.*, 2010; Garland, Jr. and Kelly, 2006).

Ecological impacts of *Cyprinus Carpio* and *Clarias Gariepinus*
Cyprinus carpio and *Clarias gariepin*us impact the environment mainly through their benthic feeding behaviour (Vilizzi and Tarkan, 2015; Kadye, 2011; Krishnakumar *et al.*, 2011), habitat alteration (Koekemoer and Steyn, 2002; Kadye, 2011), predation and aggression (Vitule *et al.*, 2008). Both fishes are benthivorous (Fig.1), scavenging the bottom of water bodies for food and causing water to become muddy as they stir the sediments looking for food items (Koekemoer and Steyn, 2002). The fish are both equipped with maxillary barbels to help them search for food items in murky water. Both of them are omnivorous in their feeding habits, eating any available food items that settle on the bottom such as pollen, seeds, insects, worms, crustaceans, molluscs, and other vegetative fragments.

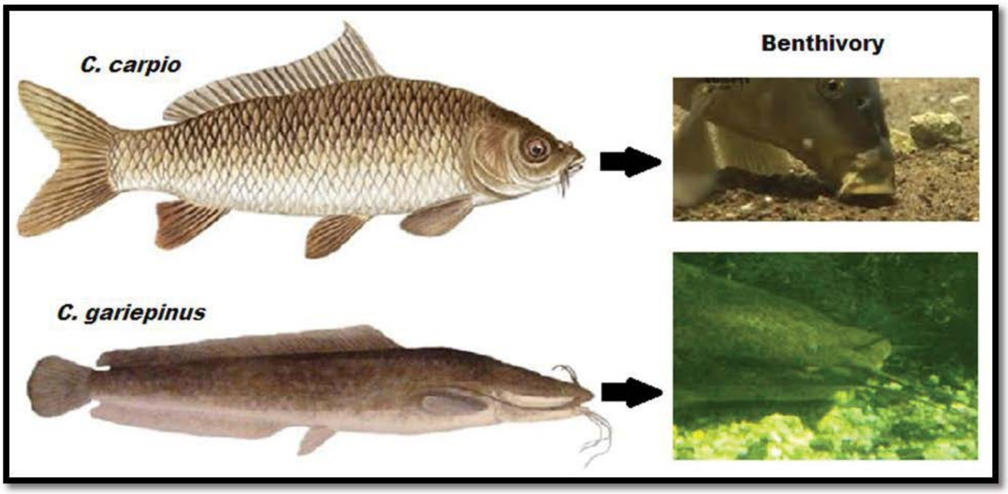

Fig. 1: Benthic activity of *C. carpio* and *C. gariepinus*

Table 2 summarizes the major impacts caused by *Cyprinus carpio* and *Clarias gariepinus* on the environment. Generally these include: increased total suspended solids, sediment resuspension; increased water column nutrient concentrations; increased biomass and altered community structure of phytoplankton; decreased submerged macrophyte and periphyton abundance; decreased large zooplankton; decreased benthic invertebrates; reduced native fish diversity and abundance; and competition with waterfowl for food resources.

Table 2. Ecological impacts of *Cyprinus carpio* and *Clarias gariepinus* and references in which they are cited

Impacts on	***Cyprinus carpio***	***Clarias gariepinus***
• Turbidity, TSS, Benthics invertebrate	Badiou *et al*., 2011; Weber and Brown, 2009; Beklioglu *et al*., 2003; Chow-Fraser, 2001; Barton *et al*., 2000	Koekemoer and Steyn, 2002; Kadye, 2011
• Sedimentation & erosion; water quality, phytoplankton, Chl. a	Badiou *et al*., 2011; Weber and Brown, 2009; Parkos III *et al*., 2003; Beklioglu *et al.,* 2003; Haas *et al*., 2007	Kadye & Booth, 2012; Koekemoer and Steyn, 2002; Kadye, 2011
• Submerged macrophytes, water fowl	Badiou *et al*., 2011; Weber and Brown, 2009; Bajer *et al*., 2009; Miller and Crowl, 2006; Zambrano, 2004	Kadye & Booth, 2012
• Zooplankton & Benthic macro-invertebrates	Badiou *et al.,* 2011; Weber and Brown, 2009; Parkos III *et al.,* 2003; Laugheed and Chow-Fraser, 2001	Kadye & Booth, 2012; Bruton, 1986
• Periphyton	Sidorkewicj *et al*., 1999.	Bruton, 1986
• Native fish diversity and abundance	Badiou et al., 2011; Miller and Beckman 1996; Taylor *et al.* 1984	Kadye & Booth, 2012; Vitule *et al.,* 2006; Bruton, 1986
• Bioturbation/Resuspension.	Huser *et al*., 2016; Ritvo *et al.,* 2004; Tatrai *et al*., 1997; Breukelaar *et al*., 1994.	Koekemoer & Steyn, 2002; Kadye, 2011

The ecological impacts in Table 2 can generally be grouped into five major categories: impacts on native fish biodiversity; bioturbation and sediment resuspension; water quality; aquatic plants (phytoplankton, periphyton, and submerged macrophytes); and aquatic invertebrates (zooplankton and benthic macro-invertebrates). A closer look at these categories of impacts may be necessary to explain mechanisms by which they are brought about.

Native fish biodiversity

One of the most cited impacts of *Cyprinus carpio* and *Clarias gariepinus* is the effect on native fish diversity through crowding out or direct replacement of native fish (Castaldelli, 2013; Corfield *et al.,* 2008; FAO Inland Water Resources and Aquaculture Service, 2003; Welcomme, 1988). Predation, resource competition for food and space, mediated by interference and aggression, as well as habitat alteration, are some of the most probable mechanisms through which these benthivorous fishes bring about their impacts on native fish fauna (Arthington, 1991).

Bioturbation

Impacts on bioturbation have also been reported (Volkenbom *et al.,* 2007; Rahman, 2006; Boyd *et al.*, 2002). Bioturbation is the churning, mixing and stirring of soils by living organisms (Eldridge and Rath, 2002; Whitford and Kay, 1999; Smallwood *et al.*, 1998). The process has profound physical, chemical and biotic implications on the environment, and can cause alterations in the structure and function of an ecosystem. Thus, bioturbation is a case of ecosystem engineering (Levinton, 1995). In the terrestrial environment, burrowing animals such as earthworms, termites, rodents, and gophers dig up soil and mix it around, causing changes to the structure of soil and its nutrient fluxes (Gabet *et al.,* 2003). In aquatic systems, the benthic activity of fish and other organisms stir and re-suspend sediments (Boyd *et al.*, 2002), increasing turbidity (Beveridge *et al*., 1994; Boyd *et al.*, 2002), benthic aeration (Ritvo *et al.*, 2004; Boyd, 1995; Boyd et al., 2002), benthic aerobic oxidation (Lucas and Southgate, 2012; Avnimelech *et al.,* 1999; Hargreaves, 1998; Scheffer, 1997), nutrient levels in water column (Volkenbom *et al.,* 2007; Boyd, 1995; Boyd *et al*., 2002) and creates bottom pH conditions that are favourable for benthic fauna (Boyd *et al*., 2002).

Water quality

Benthivorous fish such as common carp, *Cyprinus carpio* and the sharptooth catfish, *Clarias gariepinus* have also been reported to affect water quality through stirring of mud (Badiou *et al*., 2011; Kloskowski, 2011; Kadye, 2011; Boyd *et al.,* 2002). Stirring the mud results in increased turbidity (Beveridge *et al.,* 1994; Boyd *et al*., 2002) and nutrient levels in water column (Volkenbom *et al.,* 2007; Boyd, 1995; Boyd *et al*., 2002). In turn, the nutrients stimulate primary production of the aquatic ecosystem with potential to cause algal bloom when in excess (Avnimelech *et al.,* 1999). Increased turbidity decreases transparency of the water body (Skubinna *et al*. 1995), sometimes resulting into low fish and submerged macrophyte production (Mischke, 2012). However, benthic activity of fish has sometimes resulted in favourable water quality regime. It enhances aeration of the benthic zone, leading to aerobic decomposition of organic matter accumulated at the bottom and preventing the development of anoxia and production of toxic reduced metabolites (Ritvo *et al*., 2004; Boyd, 1995; Boyd *et al.,* 2002). Furthermore, stirring of mud turns the organic matter and reduced chemical substances buried in sediments to the surface-water interface (SWI) where they are aerobically oxidized, further recycling nutrients for plant uptake (Lucas and Southgate, 2012; Avnimelech *et al*., 1999; Hargreaves, 1998; Scheffer, 1997).

Aquatic invertebrates

Both the common carp and the African catfish have been reported to affect zooplankton and benthic macro-invertebrates (Badiou *et al*., 2011; Weber and Brown, 2011; Kadye, 2011). These organisms are commonly used as indicators of ecological impact studies because of their ubiquity, susceptibility and differential response to ecological impacts (Kadye, 2011). Zooplankton and benthic macroinvertebrate structure and biodiversity have been particularly affected by the presence of benthivorous fish (Batzer *et al.*, 2000; Haas *et al.*, 2007). The common carp, *Cyprinus carpio* and the sharptooth catfish, *Clarias gariepinus* have been especially noteworthy for their impacts on planktonic and benthic invertebrates. An interplay of predation and feeding behaviour, with resultant alterations in habitat, trophic structure and nutrient cycling, is a major causal mechanism of fish-induced biodiversity changes in aquatic invertebrates (Miller and Crowl, 2006).

Aquatic plants

Aquatic plants (e.g. phytoplankton, periphyton, macrophytes) are also reported to be affected by common carp and the African catfish (Badiou *et al*., 2011; Kadye, 2011; Tapia and Zambrano, 2003). Through their effects on turbidity, these fish depress light penetration, resulting in loss of benthic macrophytes which are habitat for most macro-invertebrate fauna, and reduced visual capability of zooplankton to identify food and prey (Hootsman *et al.*, 1996; Hootsman, 1999). Re-suspended nutrients result into phytoplankton blooms, which may further suppress benthic plant growth by shading light illumination (Driver *et al.*, 2005; Matsuzaki *et al*., 2009). Thus, a turbid state under carp has been associated with loss of zooplankton and benthic macro-invertebrate biodiversity (Chumchal and Drenner 2004, Bajer *et al.,* 2009). Similarly, predation and bioturbation of the sharptooth, *Clarias gariepinus*, has resulted in biodiversity loss of zooplankton and benthic macro-invertebrate (Kadye, 2011; Vitule *et al*., 2008).

Discussion and Conclusion

Our review has demonstrated that both *Cyprinus carpio* and *Clarias gariepinus* do affect aquatic ecosystems. However, it remains unclear whether the ecological impacts caused by the two fishes are similar in magnitude. Both fishes are benthivorous, and possess characteristics that predispose them to becoming invasive in non-indigenous locales. However, the notion of ecological harm and invasiveness of an organism is largely a human construct of values and perspectives, being shaped predominantly by trade-offs between gains and losses to society. Thus, a species that is considered invasive in one locale may not be so in another. Native species can be invasive, and many non-natives can be non-invasive. This complicates the determination of whether *Cyprinus carpio* and *Clarias gariepinus* are necessarily invasive in their non-native regions. For a non-native organism to be considered an invasive species in the policy context, the negative effects that the organism causes or is likely to cause are deemed to outweigh any beneficial effects (ISAC, 2006). In this context, coupled with the truism that “many alien species are non-invasive and support human livelihoods or a preferred quality of life,” Malawi’s view that *Cyprinus carpio* would be invasive in Malawi could be contentious. However, the negative ecological impacts that *Cyprinus carpio* causes need to be assessed and compared with an existing, functionally similar benthivorous fish, *Clarias gariepinus*. Such comparative study would have to be executed along the lines of the major ecological impacts identified in literature search: impacts on native fish biodiversity; bioturbation and sediment resuspension; water quality; aquatic plants (phytoplankton, periphyton, and submerged macrophytes); and aquatic invertebrates (zooplankton and benthic macro-invertebrates). The ecological impacts of common carp and the African catfish have not been compared before, although the impacts of common carp and other benthivores such as crayfish and mrigal have been compared. A comparison of ecological effects of common carp and the African catfish would contribute information to policy debates surrounding the question of whether these fishes are prohibited in their non-native regions for their invasiveness or exoticness, particularly in countries where their introduction is clearly of economic value and demanded by farmers.

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References

Ali, G., Mehmet, Y., Ayse, K. and Semra, B. 2010. Feeding properties of common carp (*Cyprinuscarpio* L. 1758) living in Hirfanli Dam Lake, Ankara, Turkey. *Aquatic Ecology* 18 (2): 545-556.

Arthington, A. H. 1991. Ecological and genetic impacts of introduced and translocated freshwater fishes in Australia. *Can. J. Fish. Aquat. Sci*. 48 (1): 33-43.

Avnimelech, Y., Kochva, M. and Hargreaves, J.A. 1999. Sedimentation and resuspension in earthen fish ponds. *J. World Aquac. Soc*. 30: 401–409.

Badiou, P., Goldsborough, L.G. and Wrubleski, D. 2011. Impacts of the common carp (*Cyprinus carpio*) on freshwater ecosystems: A review. In: Sanders, J. D. and Peterson, S. B. (Eds.) Carp: Habitat, Management and Diseases. Nova Science Publishers, Inc.

Badiou, P. H. J. and Goldsborough, L.G. 2015. Ecological impacts of an exotic benthivorous fish, the common carp (*Cyprinus carpio* L.) on water quality, sedimentation, and submerged macrophyte biomass in wetland mesocosms. *Hydrobiologia* April 2015, Vol. 748.

Bajer, P. G., Sullivan, G. and Sorensen, P. W. 2009: Effects of rapidly increasing population of common carp on vegetative cover and waterfowl in a recently restored Midwestern shallow lake. *Hydrobiologia* 632: 235–245.

Bandula, D.D. 1997. Status of the common carp, (*Cyprinus carpio*) as a candidate exotic fish for fish farming in Malawi: Report of the Technical Consultation on Species for Small Reservoir Fisheries and Aquaculture in Southern Africa.

Livingstone, Zambia, 7-11 November 1994, FAO, Harare (Zimbabwe), 1997, pp. 33-34, ALCOM report. Harare [Alcom Rep.], no. 19.

Barton, D. R., N. Kelton, and R. I. Eedy. 2000. The effects of carp (*Cyprinus carpio* L.) on sediment export from a small urban impoundment. *J. Aquat. Ecosyst. Stress Recov.* 8: 155–159

Batzer, D.P., Pusateri, C.R. and Vetter, R. 2000. Impacts of fish predation on marsh invertebrates: direct and indirect effects. *Wetlands* 20:307-312.

Batzer, D. P. 1998. Trophic interactions among detritus, benthic midges, and predatory fish in a freshwater marsh. *Ecology* 79: 1688–1698.

Beklioglu, M., Ince, O. and Tuzun, I. 2003. Restoration of the eutrophic Lake Eymir, Turkey, by biomanipulation after a major external nutrient control I. *Hydrobiologia* 490: 93–105.

Beveridge, M.C.M., Wahab, A. and Dewan, S. 1994. Effects of daily harrowing on pond soil and water nutrient levels and on rohu fingerling production. *Prog. Fish. Cult.* 56: 282-287.

Bhatnagar, A. and Devi, P., 2013. Water quality guidelines for the management of pond fish culture. *International Journal of Environmental Science*s 3: 6.

Bischof, M. M., Hanson, M. A., Fulton, M. R., Kolka, R. K., Sebestyen, S. D. and Butler, M. G. 2013. Invertebrate Community Patterns in Seasonal Ponds in Minnesota, USA: Response to Hydrologic and Environmental Variability. *Wetlands* 33: 245-256.

Boyd, C. E. 1995. Bottom Soils, Sediment, and Pond Aquaculture. Chapman and Hall, NY, USA.

Boyd, C.E., Wood, C.W. and Thunjai, T. 2002. Aquaculture pond bottom soil, quality management. Pond Dynamics/Aquaculture Collaborative Research Support Program (PD/ACRSP), Oregon State University, Oregon, USA.

Boyd, C. E. and Tucker, C. S. 1998. Pond aquaculture water quality management. Kluwer Academic Publishers, Boston, Massachusetts, 700 pp.

Bruton, M.N. and Allanson B.R. 1980. Growth of *Clarias gariepinus* in Lake Sibaya, South Africa. *South African Journal of Zoology* 15: 7-15.

Bruton, M.N. 1986. The life history styles of invasive fishes in southern Africa. In: Macdonald, I.A.W., Kruger, F.J., Ferrar, A.A. (eds.) The ecology and management of biological invasions in southern Africa, Oxford University Press, Cape Town, 201-209.

Breukelaar, A.W., Lammens, E.H.R.R., Breteler, J.G.P.K., Tatrai, I. 1994. Effects of benthivorous bream *(Abramis brama*) and carp (*Cyprinus carpio*) on sediment resuspension and concentrations of nutrients and chlorophyll a. *Freshwat. Biol.* 32: 113-121.

Bruton, M. N. 1977. The biology of *Clarias gariepinus* (Burchell, 1822) in Lake Sibaya, Kwazulu with emphasis on the role as a predator. Unpublished. Department of Zoology Institute for Freshwater Studies, Rhodes University.

Bruton, M.N. 1979a. The food and feeding behaviour of *C. gariepinus* (Pisces: Clariidae) in Lake Sibaya, S. Africa, with emphasis on its role as a predator of cichlids.

Transactions of the Zoological Society of London, 35:47-114.

Bruton, M.N. 1979b. The breeding biology and early development of *Clarias gariepinus* (Pisces: Clariidae) in Lake Sibaya, South Africa, with a review of breeding in species of the subgenus *Clarias* (*Clarias*). *Journal of Zoology* 35 (1): 1-45. DOI: 10.1111/j.1096-3642.1979.tb00056.x

Bruton, M.N. and Allanson B.R. 1980. Growth of Clarias gariepinus in Lake Sibaya, South Africa. *South African Journal of Zoology* 15: 7-15.

Bruton, M.N. 1986. The life history styles of invasive fishes in southern Africa. In: Macdonald, I.A.W., Kruger, F.J. and Ferrar, A.A. (eds.) The Ecology and Management of Biological Invasions in southern Africa, Oxford University Press, Cape Town, 201-209.

Castaldelli, G., Pluchinotta, A., Milardi, M., Lanzoni, M., Giari, L., Rossi, R. and Fano, E. A. 2013. Introduction of exotic fish species and decline of native species in the lower Po basin, north-eastern Italy. *Aquatic Conserv: Mar. Freshw. Ecosyst.* 23: 405–417. DOI: 10.1002/aqc.2345

Chumchal, M. M. and Drenner, R. W. 2004. Interrelationship between phosphorus loading and common carp in the regulation of phytoplankton. – *Arch. Hydrobiol.* 161: 147–158.

Corfield, J., Diggles, B., Jubb, C., McDowall, R. M., Moore, A., Richards, A. and Rowe, D. K. 2008. Review of the impacts of introduced ornamental fish species that have established wild populations in Australia. Prepared for the Australian Government Department of the Environment, Water, Heritage and the Arts.

De Moor, I. J. and Bruton, M. N. 1988. Atlas of alien and translocated indigenous aquatic animals in southern Africa. South African National Scientific Programmes Report 114, South Africa.

Dhawan, A. and Kaur, K. 2001. *Clarias gariepinus* in Punjab waters. Fishing Chimes, 21:56.

Driver, P. D., Closs, G.P. and Koen, T. 2005. The effects of size and density of carp (*Cyprinus carpio* L.) on water quality in an experimental pond. *Archiv fu¨r Hydrobiologie* 163: 117–131.

Engle, C.R. and Valderrama, D. 2001. Effect of stocking density on production characteristics, coasts, and risk of producing fingerlings channel catfish. *North American Journal of Aquaculture* 63: 201-207.

Eldridge, D. J. and Rath, D. 2002. Hip holes: kangaroo (*Macropus* spp.) resting sites modify the physical and chemical environment of woodland soils. *Australian J. Ecol.* 2: 527-536.

FAO Inland Water Resources and Aquaculture Services (FIRI) c2003-. Fishery Research Collection. FIGIS data collection. FAO, Rome.

FAO, 2004-2016. Cultured Aquatic Species Information Programme. *Cyprinus carpio.* Cultured Aquatic Species Information Programme. Text by Peteri, A. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 1 January 2004. [Cited 8 July 2016]. http://www.fao.org/fishery/culturedspecies/Cyprinus_carpio/en

Food and Agriculture Organization (FAO), 2015. FishStat database. FAO, Rome, Italy

Food and Agriculture Organization (FAO), 2007. Fishstat Plus (v. 2.30). FAO, Rome, Italy

Gabet, E.J., Reichman, O. J. and Seabloom, E.W. 2003. The effects of bioturbation on soil processes and sediment transport. *Annu. Rev. Earth Planet. Sci.* 31: 249-273.

Garland Jr., T. and Kelly, S.A. 2006. Phenotypic plasticity and experimental evolution. *J. Exp. Biol*. 209: 2344–2361.

Gas, N. and Noailliac-Depeyre, J. 1976. Studies on intestinal epithelium involution during prolonged fasting. *J. Ultrastruct. Res.* 56: 137–151.

Haas, K., Kohler, U., Diehl, S., Kohler, P., Dietrich, S., Holler, S., Jaensch, A., Niedermaier, M. and Vilsmeier, J. 2007. Influence of fish on habitat choice of water birds: a whole system experiment. *Ecology* 88: 2915–2925.

Hargreaves, J. A. 1998. Nitrogen biochemistry of aquaculture ponds. *Aquaculture* 166: 181-212.

Hinojosa-Garro D. and Zambrano L. 2004 Interactions of common carp (*Cyprinus carpio*) with benthic crayfish decapods in shallow ponds. *Hydrobiologia* 515: 115–122.

Hootsman, M. J. 1999. Modeling *Potamogeton pectinatus*: for better or for worse. *Hydrobiologia* 415, 7–11.

Hootsman, M. J., Drovandi, A. D., Soto Perez, N. and Weigman, F. 1996. Photosynthetic plasticity in *Potamogeton pectinatus* L. from Argentina: strategies to survive adverse light conditions. *Hydrobiologia* 340: 1–5.

Horvath, L., Tamas, G. and Seagrave, C. 2002. Carp and pond fish culture. Fishing News Books, Blackwell Scientific Publications, Oxford.

Hulata, G. 1995. A review of genetic improvement of the common carp (*Cyprinus carpio* L.) and other cyprinids by crossbreeding, hybridization and selection. *Aquaculture* 129, Issues 1–4, January 1995, Pages 143-155

Huser, B.J., Bajer, P.G., Chizinski, C.J. and Sorensen, W. 2016. Effects of common carp (*Cyprinus carpio)* on sediment mixing depth and mobile phosphorus mass in the active sediment layer of a shallow lake. *Hydrobiologia* 2016 763: 23. doi:10.1007/s10750-015-2356-4

IGFA, 2001. Database of IGFA angling records until 2001. IGFA, Fort Lauderdale, USA.

ISAC (Invasive Species Advisory Committee), 2006. Invasive Species Definition Clarification and Guidance White Paper Submitted by the Definitions Subcommittee of the Invasive Species Advisory Committee (ISAC). Approved by ISAC April 27, 2006.

ISSG (Invasive Species Specialist Group), 2000. IUCN guideline for the prevention of biodiversity loss caused by alien invasive species. IUCN, Gland.

Kadye, W.T. 2011. Assessing the impacts of invasive non-native African Sharptooth Catfish *Clarias gariepinus.* PhD Thesis. University of Rhodes. R.S.A.

Kadye, W. T. and Booth, A. J. 2012. Detecting impacts of invasive non-native sharptooth catfish, Clarias gariepinus, within invaded and non-invaded rivers. *Biodiversity and Conservation* 21: 1997–2015.

Kadye, W. T. and Booth, A. J. 2013. An invader within an altered landscape: one catfish, two rivers and an inter-basin water transfer scheme. *River Research and Applications* 29: 1131–1146. doi: 10.1002/rra.2599

Khan M.F. and Panikkar P. 2009. Assessment of impacts of invasive fishes on the food web structure and ecosystem properties of a tropical reservoir in India. *Ecological Modelling* 220: 2281-2290.

Kloskowski, J. 2011. Impact of common carp *Cyprinus carpio* on aquatic communities: direct trophic effects versus habitat deterioration. Fundam. *Appl. Limnol.* 178 (3): 245-255.

Koekemoer, J.H. and Steyn, G.J. 2002. Fish community study of Hartbeespoort dam. Final Report. Department of Agriculture, Conservation, Environment and Tourism. R.S.A.

Krishnakumar, K., Ali, A., Pereira, B. and Raghavan, R. 2011. Unregulated aquaculture and invasive alien species: A case study of the African Catfish *Clarias gariepinus* in Vembanad Lake (Ramsar Wetland), Kerala, India. *Journal of Threatened Taxa* 3 (5): 1737–1744.

Levinton, J. 1995. Bioturbators as ecosystem engineers: control of the sediment fabric, inter-individual interactions, and material fluxes. In: Linking Species and Ecosystems, Jones, C.G. and Lawton, J .H. (eds), pp. 29-36, Chapman and Hall.

Lucas, J.S. and Southgate, P. C. (Eds.), 2012. Aquaculture: Farming aquatic Animals and Plants. 2nd edn. Blackwell Publishing Ltd.

Matsuzaki, S. S., Usio, N., Takamura, N. and Washitani, I. 2009. Contrasting impacts of invasive engineers on freshwater ecosystems: an experiment and meta-analysis. *Oecologia* 158: 673–686.

Miller, A.I. and Beckman, L.G. 1996. First record of predation on white sturgeon eggs by sympatric fishes. *Transactions of the American Fisheries Society* 125:338-340.

Miller, S. A. and Crowl, T.A. 2006. Effects of common carp (*Cyprinus carpio*) on macrophytes and invertebrate communities in a shallow lake. *Freshwater Biology* 51: 85–94.

Milstein, A., Wahab, M.A. and Rahman, M.M. 2002. The effect of common carp, *Cyprinus carpio* (L.) and mrigal, *Cirrhinus mrigala* (Hamilton) as bottom feeders in major Indian carp polycultures. *Aquacult. Res.* 33: 547-556.

Mischke, C.C. (Ed.). 2012. Aquaculture Pond Fertilization: Impacts of nutrient input of production. Wiley-Blackwell, New York.

Msiska, O.V. and B.A. Costa-Pierce, Eds. 1993. History, Status and Future of Common Carp (*Cyprinus carpio* L.) as an exotic species in Malawi. WorldFish Center—ICLARM, Manila.

Mustafizur, R., Shusaku, K., Balcombe, S. and Abdul, W. 2010. Common carp *(Cyprinuscarpio* L. 1758) alters its feeding niche in response to changing food resources: direct observations in simulated ponds. *Journal of Biological Sciences* 22: 405-431.

Parkos III, J.J., Santucci Jr, V.J. and Wahl, D.H. 2003. Effects of adult common carp *(Cyprinus carpio*) on multiple 275 trophic levels in shallow mesocosms. *Can J Fish Aquat Sci* 60:182–192.

Piersma, T. and van Gils, J. A. 2010. The flexible phenotype. A Body-centred Integrative of Ecology, Physiology and Behaviour. Oxford University Press.

Poompuang, S., Na-Nakorn, U., 2004. A preliminary genetic map of walking catfish (*Clarias macrocephalus*). *Aquaculture* 232 (1):195-203.

Rahman, M.M. 2006. Food Web Interaction and Nutrients Dynamics in Polyculture Ponds. The PhD thesis, Wageningen University, the Netherlands, 157 pp.

Ramsey-Washington Metro Watershed District (RWMWD), November 2006. Phalen Chain of Lakes Carp Population Study. http://www.rwmwd.org vertical/Sites/%7BAB493DE7-F6CB-4A58-AFE0-56D80D38CD24%7D/ uploads/%7B98EF18F6-3559-47D6-BB99-B6B83F11B756%7D.PDF

Ritvo, G., Kochba, M. and Avnimelech, Y. 2004. The effects of common carp bioturbation on fishpond bottom soil. *Aquaculture* 242: 345-356.

Robins, C.R., Bailey, R.M., Bond, C.E., Brooker, J.R., Lachner, E.A., Lea, R.N. and Scott, W.B. 1991. World fishes important to North Americans. Exclusive of species from the continental waters of the United States and Canada. Am. Fish. Soc. Spec. Publ. 21: 243.

Senanan, W., Kapuscinski, A.R., Na-Nakorn, U. and Miller, L.M. 2004. Genetic impacts of hybrid catfish farming (*Clarias macrocephalus* x *C. gariepinus*) on native catfish populations in central Thailand. *Aquaculture* 235:167-184.

Scheffer, M. 1997. Ecology of Shallow Lakes. Kluwer Academic Publishing, Dordrecht, The Netherlands. 384pp.

Skubinna, J.P., Coon, T.G. and Batterson, T.R. 1995. Increased abundance and depth of submersed macrophytes in response to decreased turbidity in Saginaw Bay, Lake Huron. *J. Great Lakes Res*. 21: 476–488.

Smallwood, K. S., Morrison, M. L. and Beyea, J. 1998. Animal burrowing attributes affecting hazardous waste management. *Environmental Management* 22 (6): 831-841.

Sidorkewicj, N.S., Lopez Cazorla, A.C., Fernandez, O.A., Mockel, G.C., Burgos, M.A. 1999. Effects of Cyprinus carpio on Potamogeton pectinatus in experimental culture: the incidence of the periphyton. *Hydrobiol.* 415: 13-19

Singh, A.K., 2000. Impact of unauthorized exotic fish introduction on conservation and aquacultural development of the northeast region. In: Ponniah, A.G. and Sarkar, U.K. (eds.) Proceedings of the National Workshop on northeast Indian fish Germplasm Inventory and Conservation, Meghalaya, India: NBFGR, India, 155-156.

Sivakumaran, K., Brown, P., Stoessel, D. and Giles, A. 2003. Maturation and reproductive biology of female wild carp, *Cyprinus carpio*, in Victoria, Australia. *Environ. Biol. Fishes* 68: 321-332.

Tang, W. and Chen, Y. 2012. Hybridization between native barbless carp (*Cyprinus pellegrini*) and introduced common carp (*C. carpio*) in Xingyun Lake, China. *Zoolog Sci.* 2012 May; 29 (5): 311-8. DOI: 10.2108/zsj.29.311.

Tapia M. and Zambrano L. 2003. From aquaculture goals to real social and ecological impacts: carp introduction in rural central Mexico. *Ambio* 32: 252–257.

Tatrai, I., Olah, J., Paulovits, G., Matyas, K., Kawiecka, B.J., Jozsa, V. and Pekar, F. 1997. Biomass dependent interactions in pond ecosystems: responses of lower trophic levels to fish manipulations. *Hydrobiol.* 345: 117-129.

Vanden Bossche, J. P. and Bernacsek, G. M. 1990. Source book for the inland fishery resources of Africa: 1. *CIFA Technical Paper.* No. 18.1. Rome, FAO. 240p.

Vilizzi, L. and Tarkan, A.S. 2015. Experimental evidence for the effects of common Carp (*Cyprinus carpio* L., 1758) on freshwater ecosystems: A Narrative Review with Management Directions for Turkish Inland Waters. *LimnoFish*. 1 (3): 123-149. doi: 10.17216/LimnoFish-5000130907

Vitule, J.R.S., Umbria, S.C. and Aranha, J.M.R. 2008. Record of native amphibian predation by the alien African catfish in the Brazilian Atlantic Rain Forest. *Pan-American Journal of Aquatic Science* 3: 105-107.

Volkenbom, N., Hedtkamp, S.I.C., van Beusekom, J.E.E. and Reise, K. 2007. Effects of bioturbation and bioirrigation by lugworms (*Arenicola marina*) on physical and chemical sediment properties and implications for intertidal habitat succession. *Estuarine, Coastal and Shelf Science* 74: 331-343.

Wahab, M.A., Rahman, M.M. and Milstein, A. 2002. The effect of common carp, *Cyprinus carpio* (L.) and mrigal, *Cirrhinus mrigala* (Hamilton) as bottom feeders in major Indian carp polycultures. *Aquacult. Res.* 33: 547-556.

Weber, M. J. and Brown, M.L. 2009. Effects of Common Carp on Aquatic Ecosystems 80 Years after "Carp as a Dominant": Ecological Insights for Fisheries Management. *Reviews in Fisheries Science* 17 (4):524-537

Weber, M. J. and Brown, M. L. 2011. Relationships among invasive common carp, native fishes and physicochemical characteristics in upper Midwest (USA) lakes. *Ecology of Freshwater Fish* 20: 270–278.

Weir, J. S. 1972. Diversity and abundance of aquatic insects reduced by introduction of the fish Clarias gariepinus to pools in central Africa. *Biological Conservation* 4: 169–175.

Welcomme, R. L. 1988. International Introductions of Inland Aquatic Species. FAO, U.N.

Whitford, W. G. and Kay, F. R. 1999. Bioperturbation by mammals in deserts: a review. *Journal of Arid Environments* 41: 203-230.

Yalçin, ¸S. Ö., Akyurt, ˙I. and Solak, K. 2001. Stomach contents of the catfish (*Clarias gariepinus* Burchell, 1822) in the River Asi (Turkey). *Turkish Journal of Zoology* 25, 461–468.

Zhou, J. F., Wu, Q. J., Ye, Y. Z. and Tong, J. G. 2003. Genetic divergence between *Cyprinus carpio carpio* and *Cyprinus carpio* haematopterus as assessed by mitochondrial DNA analysis, with emphasis on origin of European domestic carp. *Genetica* 119:93–97