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Ecological Impacts of Common Carp Invasions: A Global Perspective

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Abstract As an invasive species that is widely spread globally, common carp (*Cyprinus carpio*) has caused significant ecological impacts on aquatic ecosystems. The invasion of carp has not only disrupted the ecological balance in many areas, but has also had an economic impact on commercial and recreational fishing, increasing the cost of management and control. This study examines the global status of carp invasion and explores its ecological consequences on the destruction of native species, changes in food web dynamics, and impacts on water quality and sediments. This paper analyzes several cases to show the diversity impacts of carp invasions and the current management strategies, including physical removal, biological control and policy supervision, in order to provide an important theoretical basis for the integrated management of carp invasions and put forward the direction of future research.
Keywords Carp invasion; Ecological impacts; Aquatic ecosystems; Biodiversity conservation; Management strategy

1 Introduction

The common carp (*Cyprinus carpio*), originally native to Eurasia, is one of the most widely distributed freshwater fish species globally. Its introduction to various regions has been driven by aquaculture, recreational fishing, and ornamental purposes. The species exhibits traits such as high fecundity, adaptability to diverse environmental conditions, and a generalist diet, which contribute to its success as an invasive species (Crichigno et al., 2016). In regions like Australia, the common carp has become the most abundant large freshwater fish, significantly altering local ecosystems (Koeh, 2004). Similarly, in the Mediterranean region, historical, economic, and cultural factors have facilitated its spread, impacting native aquatic systems (Vilizzi, 2012).

Invasive species, such as the common carp, pose significant threats to biodiversity, ecosystem services, and local economies. The global spread of common carp has been well-documented, with established populations in North and South America, Australia, and various parts of Europe and Asia (Nedoluzhko et al., 2021). Ecological niche modeling has shown that common carp can potentially invade a wide range of habitats, from temperate regions to high mountain tropical aquatic systems (Oh et al., 2023). In South America, for instance, the species has expanded its range westward into the Andean region, demonstrating its ability to colonize new environments (Ruppert et al., 2017). The rapid spread and establishment of common carp in diverse regions underscore the need for effective management strategies to mitigate its ecological impacts.

This study provides a comprehensive overview of the ecological impacts of carp invasion from a global perspective. To summarize the current distribution and distribution of carp in various regions of the world; assess the ecological consequences of carp invasions on native species and ecosystems; Identify knowledge gaps and propose future research directions to better understand and manage the impacts of common carp invasions. Synthesizing information from multiple studies will contribute to a better understanding of the global ecological impacts of carp and inform policy and management decisions to protect native biodiversity and ecosystem health.

2 Historical Context of Common Carp Invasions

2.1 Origin and natural habitat

The common carp (*Cyprinus carpio*) is native to the Ponto-Caspian and Far Eastern regions, as well as northern

Vietnam (Nedoluzhko et al., 2021). Historically, wild populations of genetically pure ancestors are still found in confined areas of Thrace and Northern Anatolia, and possibly in eastern parts of Greece (Vilizzi, 2012). These regions represent the natural habitat where the species evolved and adapted to local environmental conditions.

2.2 Introduction to non-native environments

The introduction of common carp to non-native environments has been driven by a combination of historical, economic, and cultural motives. Since Roman times, common carp have been translocated throughout the Mediterranean region for aquaculture and recreational purposes (Vilizzi, 2012). In North and South America, introductions stem from aquaculture facilities and historical introductions for recreational angling. Similarly, in Australia, the species was introduced and has since become the most abundant large freshwater fish in south-east Australia (Crichigno et al., 2016).

2.3 Patterns of spread across different continents

The spread of common carp across different continents has followed distinct patterns influenced by environmental conditions and human activities. In the Americas, the distributional potential of common carp covers most temperate regions and high mountain tropical aquatic systems. In southern South America, the species has expanded westward into the Andean Region and established well in the southernmost populations (Vilizzi et al., 2015). In Australia, common carp have spread rapidly and now dominate fish communities over more than 1 million km². The species' success as an invader is attributed to its multiple traits that favor invasion and the degradation of aquatic environments that give it a relative advantage over native species (Samsing et al., 2021).

The global perspective on common carp invasions highlights the species' adaptability and the profound ecological impacts it can have on native aquatic faunas. Understanding the historical context and patterns of spread is crucial for developing effective management strategies to mitigate the negative consequences of these invasions.

3 Ecological Impacts on Aquatic Ecosystems

3.1 Disruption of native species

3.1.1 Competition for resources

Common carp (*Cyprinus carpio*) are known to compete with native fish species for resources, significantly impacting their growth and survival. In mesocosm experiments, the presence of common carp reduced the growth of native fish species, although this effect was mitigated by higher native species diversity (Gallardo et al., 2016). Additionally, in Australian dryland rivers, carp monopolized food resources, leading to a decrease in native fish biomass (Marshall et al., 2019). This competition for resources can lead to significant declines in native fish populations, particularly in ecosystems where carp densities are high (Collins et al., 2017).

3.1.2 Predation on native fish

Common carp can also directly impact native fish populations through predation. In some ecosystems, carp have been observed to prey on native fish eggs and juveniles, further exacerbating their decline. For example, in Australian dryland rivers, the predation by carp has been linked to the extirpation of an endangered river snail (Marshall et al., 2019). This predatory behavior, combined with their competitive nature, makes common carp a significant threat to native fish species.

3.1.3 Habitat modification

Common carp are notorious for their ability to modify habitats, often leading to detrimental effects on native species. Their benthic foraging behavior increases water turbidity and uproots aquatic macrophytes, transforming clear-water lakes into turbid ones (Rolls et al., 2107). This habitat modification not only reduces the availability of suitable habitats for native species but also alters the entire ecosystem's structure and function. In shallow lakes, the presence of common carp has been associated with a shift from macrophyte-dominated clear water states to phytoplankton-dominated turbid states (Matsuzaki et al., 2008).

3.2 Alteration of food web dynamics

The introduction of common carp into aquatic ecosystems can lead to significant alterations in food web dynamics.

Carp's feeding habits can reduce the abundance of zooplankton and benthic invertebrates, which are crucial components of the aquatic food web (Rolls et al., 2107). This reduction in prey availability can have cascading effects throughout the food web, impacting higher trophic levels, including native fish species. Additionally, the presence of carp can increase phytoplankton abundance due to reduced grazing pressure from zooplankton, further altering the food web structure (Carey and Wahl, 2010).

3.3 Impact on water quality and sediment

Common carp significantly impact water quality and sediment composition in invaded ecosystems. Their foraging behavior increases water turbidity and nutrient concentrations, leading to eutrophication and degraded water quality (Marshall et al., 2019). In shallow lakes, carp have been shown to increase suspended solids, phytoplankton, and nutrient levels, contributing to a shift from clear to turbid water states (Carey and Wahl, 2010). These changes in water quality can have far-reaching consequences for the entire aquatic ecosystem, affecting both biotic and abiotic components.

4 Economic and Social Consequences

4.1 Impact on commercial and recreational fishing

The invasion of common carp (*Cyprinus carpio*) has significant repercussions on both commercial and recreational fishing sectors. In Germany, for instance, specialized carp anglers' catch rates exceed commercial harvests by up to 2500%, indicating a substantial impact on the fishing industry. This overabundance of carp can lead to decreased populations of native fish species, thereby reducing the overall biodiversity and altering the ecosystem balance, which in turn affects commercial fishing yields (Busst et al., 2017). Additionally, the presence of carp can shift ecosystems from macrophyte-dominated clear water states to turbid water states dominated by phytoplankton, further complicating fishing activities and reducing the quality of fishing experiences (Gallardo et al., 2016).

4.2 Economic costs of management and control

Managing and controlling the spread of common carp incurs significant economic costs. Invasive species like the common carp have been responsible for economic losses amounting to at least US$37.08 billion globally, with North America bearing the highest costs (Haubrock et al., 2021). These costs are associated with damage and resource losses, as well as expenses related to management actions and environmental restoration. In Australia, for example, the control of carp populations in dryland rivers involves substantial investments in biocontrol measures, which are necessary to mitigate their adverse effects on native fish biomass and ecosystem health (Marshall et al., 2019). Moreover, the implementation of continuous removal efforts and novel control approaches is essential to prevent the unintended consequences of increased carp condition and reproductive potential (Coulter et al., 2018).

4.3 Social perceptions and cultural significance

The social perceptions and cultural significance of common carp vary across different regions. In some areas, carp are valued for recreational fishing, contributing to local economies through tourism and related activities (Veer and Nentwig, 2015). However, the negative ecological impacts of carp invasions, such as increased water turbidity and reduced native fish populations, can lead to negative social perceptions and a demand for effective management strategies (Figure 1). Policymakers must consider these social welfare implications when deciding on conservation policies and mitigation efforts (Brockmann et al., 2021). Additionally, the cultural significance of carp in certain communities may influence the acceptance and success of management programs, highlighting the need for culturally sensitive approaches to invasive species control.

5 Case Studies of Common Carp Invasions

5.1 North America

In North America, the introduction of common carp (*Cyprinus carpio*) has led to significant ecological changes in various aquatic ecosystems. The carp's presence has been linked to a decline in aquatic plant richness and cover, particularly in the Great Plains and Eastern Temperate Forests ecoregions. Studies have shown that as carp biomass increases, submersed plant cover and species richness decline exponentially, with plant cover reduced to less than 10% and species richness halved in lakes where carp biomass exceeds 190 kg/ha (Bajer et al., 2016). Additionally, the presence of carp has been associated with increased water turbidity and nutrient levels, which further degrade water quality and aquatic habitats.

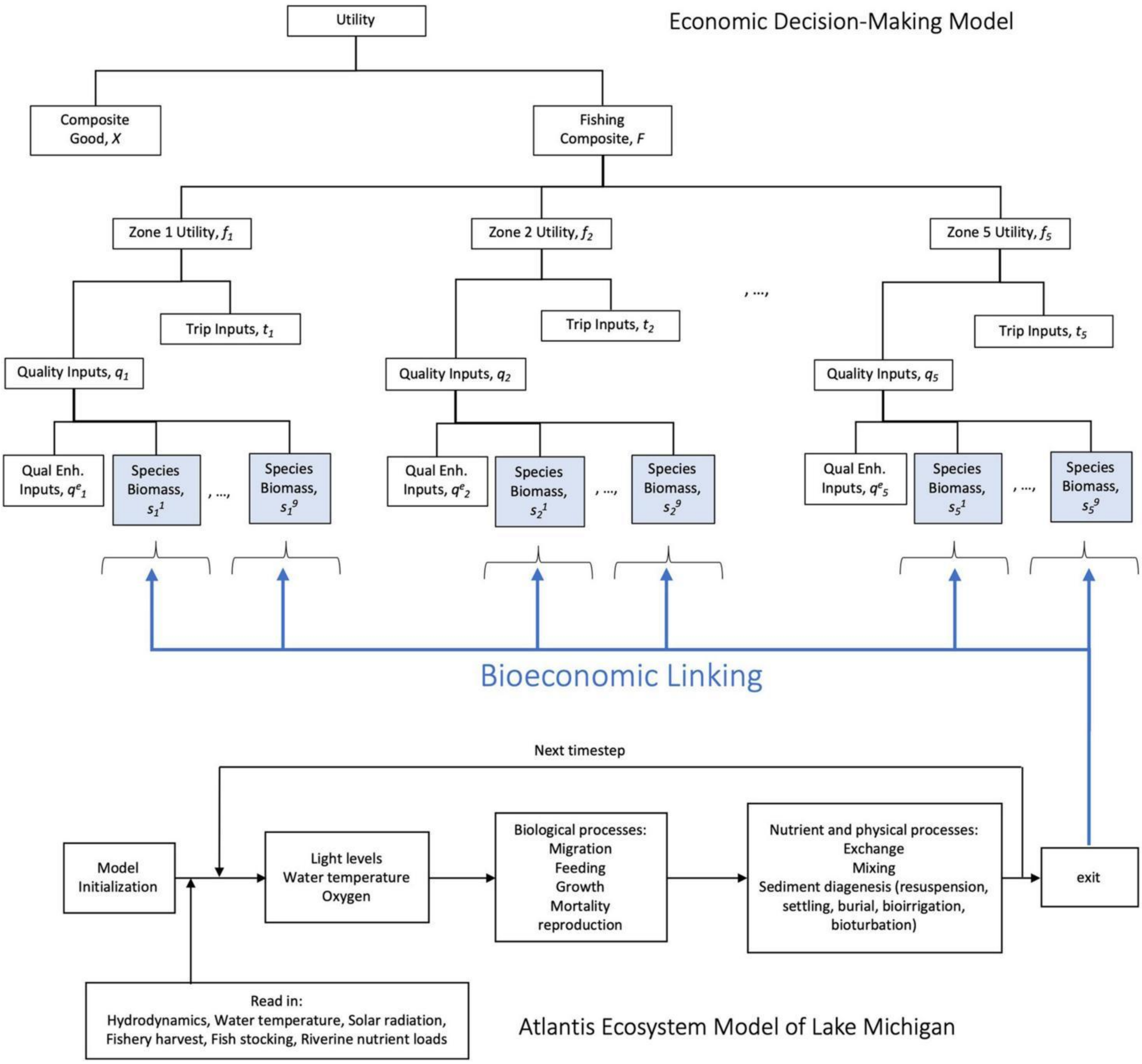

Figure 1 Schematic representation of the Bioeconomic Model. Economic utility or wellbeing is a nested function of space and species-specific decisions, which depend on the linked ecological models-the complex Atlantis model, or the simplified model (Adopted from Brockmann et al., 2021)

The impact of common carp on native fish populations has also been documented. For instance, in the Murray-Darling Basin, Australia, carp have been shown to monopolize food resources, leading to a significant reduction in native fish biomass (Marshall et al., 2019). In North America, similar patterns have been observed, with carp outcompeting native species for resources and altering the structure of aquatic communities (Thresher et al., 2018).

5.2 Europe

In Europe, the introduction of common carp has similarly resulted in ecological disruptions. The carp's benthivorous feeding habits disturb sediment and uproot aquatic plants, leading to increased water turbidity and a decline in macrophyte abundance. This has been observed in various European water bodies, where the presence of carp has led to a shift from clear water states dominated by macrophytes to turbid water states dominated by phytoplankton (Gallardo et al., 2016).

The ecological impacts of common carp in Europe are not limited to changes in water quality and plant communities. The introduction of carp has also been associated with the spread of invasive parasites, such as the tapeworm Atractolytocestus huronensis, which has been introduced to Europe along with its host. This parasite poses a threat to both feral and cultured fish populations, highlighting the broader ecological consequences of carp invasions (Costa et al., 2021).

5.3 Australia

In Australia, common carp have become a major pest, particularly in the Murray-Darling Basin, where they now constitute up to 90% of fish biomass. The ecological impacts of carp in this region include increased water turbidity, reduced macrophyte density, and changes in macroinvertebrate and native fish assemblages. However, some expected impacts, such as increased turbidity and reduced macroinvertebrate density, were not observed in dryland rivers, suggesting that the general understanding of carp impact requires modification for these specific ecosystems (Figure 2) (Marshall et al., 2019).

Efforts to control carp populations in Australia have included the proposed use of *Cyprinid Herpesvirus-3* (CyHV-3) as a biological control agent. However, studies have shown that the virus has not yet been detected in the Murray-Darling Basin, and there is little evidence of virus transmission between invasive and native fish species. This highlights the need for careful consideration of ecological context and potential unintended consequences when implementing biocontrol measures (Costa et al., 2021).

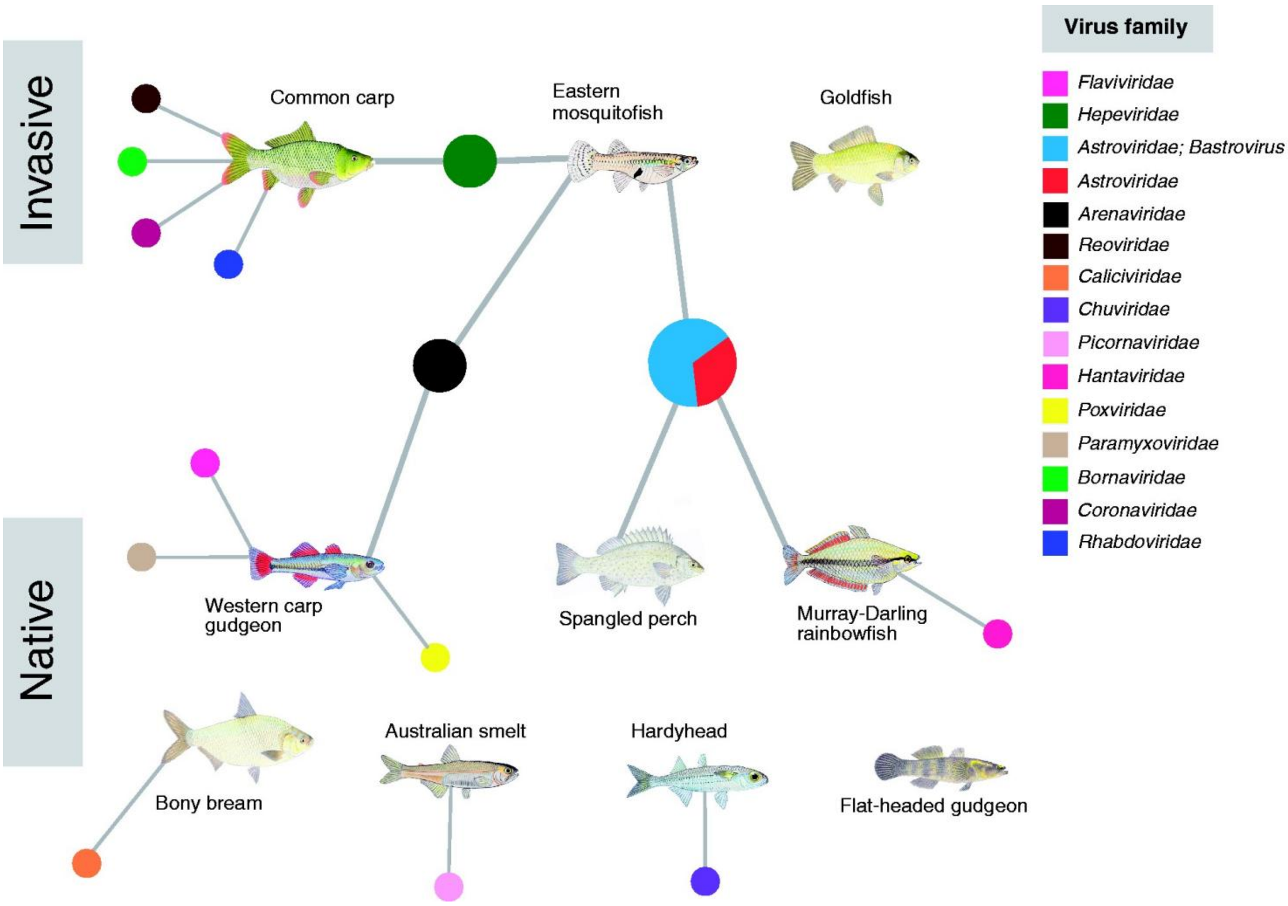

Figure 2 Network diagram displaying vertebrate-associated viruses identified in native and invasive freshwater fish (Adopted from Costa et al., 2021)

Image caption: Colours of each node represent a virus family. Both goldfish and flat-headed gudgeon contained non-vertebrate-associated viruses (Adopted from Costa et al., 2021)

6 Management and Control Strategies

6.1 Physical removal and habitat modification

Physical removal and habitat modification are common strategies employed to manage invasive common carp populations. Techniques such as netting, electrofishing, and trapping are frequently used to physically remove carp from aquatic ecosystems. For instance, targeting winter aggregations of adult carp for removal has been identified as an effective strategy (Bajer et al., 2019). Habitat modification, such as altering water levels or modifying substrates, can also reduce carp populations by disrupting their breeding and feeding habitats (Coulter et al., 2018). However, these methods often require continuous effort and can be labor-intensive.

6.2 Biological control methods

6.2.1 Use of predators and competitors

Biological control through the introduction or enhancement of natural predators and competitors is another strategy. Native predators, such as certain fish species, can help control carp populations by preying on their eggs and larvae (Busst and Britton, 2017). For example, stocking native predators has been successful in controlling juvenile invasive species like the rusty crayfish. However, the effectiveness of this method can vary depending on the specific ecosystem and the presence of suitable predator species.

6.2.2 Sterilization and genetic approaches

Sterilization and genetic approaches are emerging as promising methods for controlling invasive carp populations (Feng, 2024). Techniques such as the release of sterilized males or the use of genetic modifications to reduce reproductive success are being explored. In Australia, there are ongoing investigations into the use of a virus to control carp populations. These methods aim to reduce the reproductive capacity of carp, thereby gradually decreasing their numbers over time.

6.2.3 Environmental manipulation

Environmental manipulation involves altering the conditions of the habitat to make it less favorable for carp. This can include changes in water quality, such as increasing turbidity or altering nutrient levels, which can negatively impact carp while benefiting native species (Cupp et al., 2021). For example, increasing water turbidity has been shown to reduce carp abundance by disrupting their feeding and breeding behaviors. However, these methods must be carefully managed to avoid unintended consequences on the broader ecosystem.

6.3 Policy and regulatory frameworks

Effective management of invasive carp also requires robust policy and regulatory frameworks. These frameworks can include regulations on the transport and release of carp, as well as policies that support the implementation of control measures. Integrated pest management (IPM) plans, which combine multiple control strategies, are being developed by natural resource agencies to address the complex challenges posed by invasive carp (Figure 3) (Kulhanek et al., 2011). Additionally, international cooperation and consistent enforcement of regulations are crucial for preventing the spread of carp across borders and ensuring the success of management efforts (Rytwinski et al., 2019).

7 Ecological and Environmental Considerations

7.1 Long-term ecological effects

The long-term ecological effects of common carp (*Cyprinus carpio*) invasions are profound and multifaceted. Invasive species like common carp can cause significant shifts in ecosystem structure and function. For instance, common carp have been shown to increase water turbidity and nutrient levels, leading to eutrophication and a decline in water quality (Gallardo et al., 2016). These changes can result in stable-state shifts from clear water, macrophyte-dominated systems to turbid, phytoplankton-dominated systems, which are less hospitable to native species. Additionally, the presence of common carp can lead to a reduction in the abundance of benthic macroinvertebrates and submerged macrophytes, further altering the ecosystem. Over time, these changes can lead to a decrease in native fish biomass and biodiversity, as seen in Australian dryland rivers where carp monopolize food resources (Marshall et al., 2019).

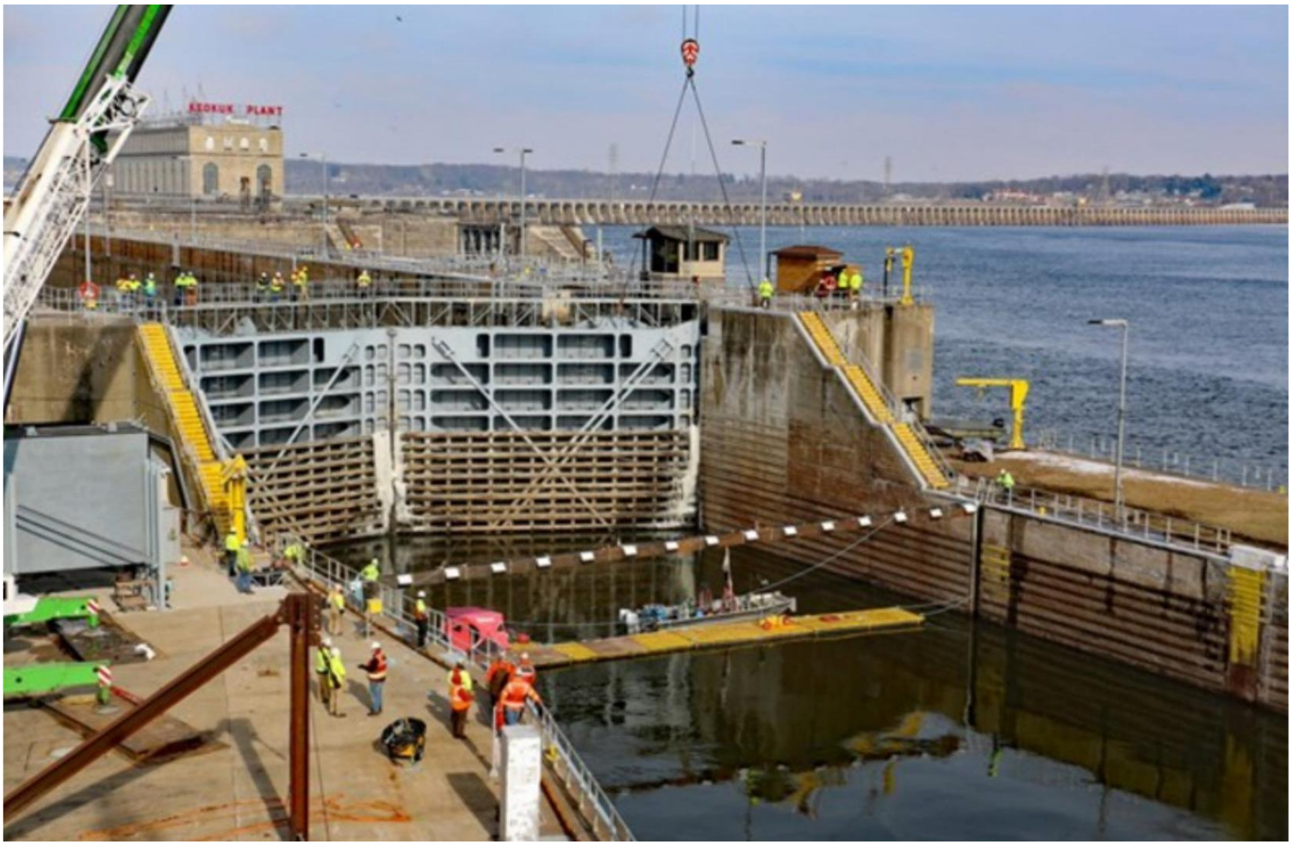

Figure 3 Underwater acoustic deterrence system (uADS) to assess its effectiveness in reducing the upstream passage of invasive carp (Adopted from Cupp et al., 2021)

7.2 Impact on biodiversity conservation

The impact of common carp on biodiversity conservation is significant. Invasive carp can outcompete native species for resources, leading to declines in native fish populations and overall biodiversity (Britton, 2022). For example, in mesocosm experiments, the presence of common carp reduced the growth of native fish species, although this effect was mitigated by higher native species richness. Furthermore, common carp invasions can lead to the extirpation of sensitive species, such as the endangered river snail in Australian rivers, due to predation and habitat alteration (Marshall et al., 2019). The introduction of common carp can also cause genetic introgression and the transmission of non-native pathogens, further threatening native biodiversity. These impacts underscore the importance of managing common carp populations to preserve native biodiversity and ecosystem function.

7.3 Climate change and invasive potential

Climate change is expected to exacerbate the invasive potential of common carp. As global temperatures rise, the range of suitable habitats for common carp is likely to expand, increasing the risk of invasion in new areas (Závorka et al., 2018). Climate change can also alter hydrological cycles and nutrient dynamics, creating conditions that favor the establishment and spread of invasive species like common carp. For instance, increased water temperatures and nutrient availability can enhance the growth and reproductive success of common carp, further facilitating their invasion. Additionally, the combined effects of climate change and biological invasions can lead to more severe ecological impacts, such as altered food web dynamics and reduced ecosystem resilience (Shackleton et al., 2018). Therefore, understanding the interactive effects of climate change and invasive species is crucial for predicting and managing future invasions.

8 Concluding Remarks

The invasion of common carp (*Cyprinus carpio*) has been shown to significantly impact aquatic ecosystems globally. Key findings from the reviewed literature indicate that common carp invasions lead to increased water turbidity, elevated nutrient levels, and reduced abundance of macrophytes, zooplankton, and native fish species. These changes often result in a shift from clear water states dominated by macrophytes to turbid water states dominated by phytoplankton, which can have cascading effects on the entire aquatic food web. Additionally, carp invasions have been linked to the decline in species richness and cover of aquatic plants, particularly in regions where carp biomass exceeds critical thresholds. The impacts of carp are not uniform across all ecosystems, with some variations observed based on local environmental conditions and the presence of other stressors.

Integrated management approaches are crucial for mitigating the ecological impacts of common carp invasions. Effective management strategies should combine multiple control methods, including biocontrol agents like cyprinid herpesvirus 3 (CyHV-3), physical removal, and habitat modification. The use of integrated pest management (IPM) plans that incorporate behavioral deterrents, barriers, and efficient removal techniques can help limit the spread and reduce the population of invasive carp. Additionally, understanding the specific characteristics of the invaded ecosystems and tailoring management practices to local conditions can enhance the effectiveness of these strategies. Continuous monitoring and adaptive management are essential to address the dynamic nature of carp invasions and to mitigate unintended consequences, such as the potential release from density-dependent competition.

Future research should focus on several key areas to improve the management and understanding of common carp invasions. Experts need to conduct more comprehensive studies to examine the long-term ecological impacts of carp in different habitats and environmental conditions. Research should explore the development and implementation of novel biocontrol agents and integrated management technologies, and assess their efficacy and potential ecological consequences; Investigate interactions between carp and other invasive species to understand compounding impacts on native ecosystems. Finally, prediction models that incorporate invasion history, biomass, and environmental variables should be improved to predict the impact of carp invasions and guide management decisions. By filling these research gaps, we can develop more effective strategies to mitigate the ecological impacts of carp and protect aquatic biodiversity.

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Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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