

Tilapia (*Oreochromis* spp.) as an Ecological Threat to Indigenous Fish Diversity in Indian Rivers and Reservoirs: Mechanisms, Evidence and Management Perspectives

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Abstract— The introduction and subsequent establishment of non-native tilapias in freshwater ecosystems have generated increasing ecological and fisheries-management concerns in India. Species belonging to the genus *Oreochromis*, particularly Nile tilapia (*Oreochromis niloticus*) and Mozambique tilapia (*O. mossambicus*), possess a combination of biological characteristics—including broad environmental tolerance, trophic plasticity, early sexual maturation, repeated reproduction, parental care and the capacity to exploit disturbed habitats—that can facilitate establishment outside their native ranges. Although tilapia are economically important aquaculture species and can contribute substantially to food production and rural livelihoods, their occurrence in open rivers and reservoirs presents a potential challenge for the conservation of indigenous fish assemblages when populations become established at high abundance.

This review synthesizes available evidence on the ecological interactions between introduced tilapias and indigenous fishes in Indian rivers and reservoirs. Particular attention is given to competition for food and space, overlap in trophic niches, occupation of spawning and nursery habitats, potential effects on recruitment, modification of benthic and littoral habitats, and changes in fish-community structure. Evidence from Indian systems indicates that ecological responses are not uniform. Historical observations from Kabini Reservoir and other water bodies have associated tilapia establishment with changes in the abundance of indigenous fishes, whereas food-web modelling in a tropical Indian reservoir demonstrated that *O. mossambicus* negatively affected indigenous catfishes but *O. niloticus* did not produce uniformly negative effects across fish groups (Khan and Panikkar, 2009). More recent investigations provide evidence of rapid establishment in Panam Reservoir, Gujarat, where *O. niloticus* increased to more than 20% of the reported catch by 2023 following an apparent escape from cage culture, and of trophic plasticity in *O. mossambicus* in the Bhima River (Sajina et al., 2026; Khare et al., 2026).

The available evidence supports a precautionary and ecosystem-specific approach rather than assuming that all tilapia populations inevitably produce identical ecological outcomes. Effective management should combine prevention of escape, pathway regulation, early detection, systematic fisheries monitoring, ecological risk assessment, targeted population control where justified, and responsible aquaculture biosecurity. Further research using standardized long-term datasets, stable-isotope analysis, molecular approaches, recruitment studies and ecosystem modelling is required to distinguish correlation from causation and to quantify the consequences of tilapia establishment for indigenous fish diversity and fisheries production in Indian inland waters.

Keywords— *Oreochromis niloticus*; *Oreochromis mossambicus*; invasive fish; indigenous fish diversity; trophic competition; river fisheries; reservoir fisheries; aquaculture escape; ecological impact; India.

I. INTRODUCTION

Biological invasions are recognized as an important component of global environmental change because introduced organisms can alter species interactions, community composition, ecosystem processes and the economic value of natural resources. Freshwater ecosystems are particularly vulnerable because they are highly connected through rivers, canals, reservoirs and aquaculture infrastructure, while human-mediated translocation of fish species can occur repeatedly across drainage basins. Fish introductions have historically been undertaken for aquaculture, fisheries enhancement, ornamental purposes, biological control and other management objectives. Once established in open waters, however, some introduced species can persist and disperse beyond the original point of introduction.

Tilapias are among the most widely translocated freshwater fishes globally. Their importance in aquaculture is associated with rapid growth, efficient utilization of relatively low-trophic-level food resources, tolerance of a broad range of environmental conditions and comparatively simple culture requirements (El-Sayed and Fitzsimmons, 2023). These characteristics have supported the expansion of tilapia production in many tropical and subtropical regions. At the same time, the same biological attributes may facilitate establishment when tilapia gain access to natural or semi-natural aquatic ecosystems.

In India, tilapias have a long history of introduction and culture. *Oreochromis mossambicus* was introduced into Indian waters during the twentieth century and subsequently became established in several freshwater systems. *O. niloticus* has also been introduced and cultured in different parts of the country. The ecological significance of these introductions varies considerably among water bodies. In some systems, tilapia contribute to fisheries production without clear evidence of substantial ecological disruption. In other systems, their increasing abundance has coincided with changes in the relative representation of indigenous species, raising concerns regarding competition, habitat use and fisheries productivity.

The distinction between association and causation is particularly important in evaluating these effects. A decline in a native fish population following the establishment of tilapia does not, by itself, demonstrate that tilapia caused the decline. Reservoir construction, altered hydrology, eutrophication, fishing pressure, habitat modification, pollution, climate variability and other introduced species may act simultaneously. Consequently, ecological assessments should consider tilapia as one component of a broader set of environmental and anthropogenic drivers.

Historical evidence nevertheless indicates that interactions between tilapia and indigenous fishes deserve attention. FAO's review of Indian reservoir fisheries documented concerns regarding competition between tilapia and indigenous carps and reported a decline in the catch contribution of *Cirrhinus reba* in Kabini Reservoir during the early 1980s following tilapia establishment (FAO, 1997). More recent work has demonstrated that the ecological consequences can differ among species and ecosystems. Khan and Panikkar (2009), using a trophic network model for a tropical Indian reservoir, found adverse effects of Mozambique tilapia on indigenous catfishes, whereas Nile tilapia did not negatively affect the fish groups examined and showed a positive modelled interaction with Indian major carps.

Recent Indian studies further illustrate the need for continued investigation. Trivedi et al. (2021) documented the established occurrence of Nile tilapia among exotic fishes in the Yamuna River system. In Panam Reservoir, Gujarat, Sajina et al. (2026) documented a rapid increase of Nile tilapia following an apparent escape from cage culture, with the species accounting for more than 20% of the total catch by 2023. In the Bhima River, Khare et al. (2026) found that Mozambique tilapia exhibited a flexible, predominantly zooplanktivorous–omnivorous feeding strategy, indicating potential trophic overlap with native planktivorous fishes.

The objective of this review is therefore to examine the ecological significance of *Oreochromis* spp. in Indian rivers and reservoirs, with particular emphasis on mechanisms of interaction with indigenous fish communities, available empirical evidence, fisheries implications, management options and research priorities.

II. TILAPIA SPECIES OF ECOLOGICAL CONCERN IN INDIA

The term "tilapia" encompasses several cichlid species, but *Oreochromis niloticus* and *O. mossambicus* are particularly relevant to discussions of introduced tilapias in Indian inland waters.

2.1 Nile tilapia (*Oreochromis niloticus*)

Nile tilapia is an African cichlid that has become one of the world's most important aquaculture fishes. Its global distribution has expanded substantially as a consequence of deliberate introductions for aquaculture and fisheries development. Its

commercial importance is associated with rapid growth, adaptability and broad dietary capacity (El-Sayed and Fitzsimmons, 2023).

The ecological characteristics of *O. niloticus* are relevant to invasion risk. The species can exploit planktonic, periphytic, plant-derived and other food resources, while reproductive behaviour involving nest construction, parental care and repeated spawning can facilitate population establishment under suitable conditions. Its ecological effects, however, depend strongly on recipient ecosystem characteristics and interactions with resident species.

2.2 Mozambique tilapia (*Oreochromis mossambicus*)

Mozambique tilapia is another widely introduced species. It is capable of utilizing diverse food resources and can persist under environmental conditions that may limit some native species. Recent evidence from the Bhima River demonstrates considerable dietary flexibility, with juvenile and adult fish differing in prey use and DNA metabarcoding identifying a broader range of food items than conventional stomach-content analysis alone (Khare et al., 2026). Such trophic flexibility may increase the capacity of the species to exploit available resources following establishment.

III. PATHWAYS OF INTRODUCTION AND ESTABLISHMENT

The establishment of non-native fish populations generally requires several stages: introduction, survival, reproduction, population growth and dispersal. Aquaculture is an important pathway because culture facilities may be hydraulically connected to rivers, reservoirs, irrigation channels and flood-prone landscapes.

Escape can occur through flooding, structural failure, handling operations, harvesting activities, accidental release and inadequate containment. Cage culture presents a particularly important pathway where cages are installed directly within reservoirs or other open water bodies. The recent investigation of Panam Reservoir provides a clear Indian example. Sajina et al. (2026) traced the introduction of *O. niloticus* to an apparent accidental escape associated with cage culture initiated in 2018, followed by a major loss event in 2019. The species was initially recorded sporadically but increased rapidly, contributing more than 20% of the total catch by 2023.

This case demonstrates that introduction pathway management should be considered an integral component of fisheries management. Once an established breeding population develops, eradication from a large reservoir or river is likely to become considerably more difficult than preventing the initial escape.

Other pathways may include unauthorized stocking, release of unwanted cultured fish, movement through interconnected waterways and intentional introductions. Therefore, risk assessment should extend beyond individual farms to include the complete aquatic landscape within which production facilities operate.

IV. BIOLOGICAL CHARACTERISTICS ASSOCIATED WITH ESTABLISHMENT SUCCESS

The potential ecological success of introduced tilapias can be understood through several interacting biological characteristics.

4.1 Environmental tolerance

Tilapias are generally capable of surviving under a relatively broad range of environmental conditions. This tolerance may facilitate persistence in disturbed, nutrient-enriched or otherwise modified aquatic systems. El-Sayed and Fitzsimmons (2023) emphasized that the ability of Nile tilapia to tolerate diverse environmental conditions has contributed to its global distribution.

However, environmental tolerance should not be interpreted as unlimited physiological tolerance. Establishment remains dependent on temperature, oxygen availability, salinity, food resources, habitat availability and seasonal conditions.

4.2 Reproductive capacity

High reproductive output can accelerate population establishment. Tilapias possess reproductive strategies that include nest construction, parental care and, in *Oreochromis*, mouthbrooding. Such parental investment may enhance offspring survival relative to fishes lacking parental protection.

Repeated reproductive events can allow populations to recover rapidly from moderate mortality. Consequently, fishing pressure may not necessarily produce proportional reductions in population abundance if reproductive recruitment remains high.

4.3 Trophic plasticity

Dietary flexibility is particularly important in novel ecosystems because it allows introduced fish to exploit resources that may fluctuate seasonally or spatially. Tilapias can consume phytoplankton, periphyton, zooplankton, detrital material, plant-associated organisms and various invertebrates.

The Bhima River study provides recent evidence for such flexibility. Khare et al. (2026) found that Mozambique tilapia showed a predominantly zooplanktivorous–omnivorous feeding strategy, with juveniles relying relatively more on microinvertebrates and adults showing broader dietary utilization.

4.4 Behavioural adaptability

Tilapia can exploit littoral habitats, vegetated areas and shallow zones for feeding and reproduction. Their ability to modify habitat use in response to environmental conditions may facilitate persistence in reservoirs where habitat conditions vary considerably among seasons.

4.5 Compatibility with human-modified environments

Reservoirs, irrigation systems, urban water bodies and nutrient-enriched freshwater systems often differ substantially from undisturbed riverine habitats. Species capable of exploiting such modified environments may gain an advantage over habitat-specialist native fishes.

This does not imply that tilapia are universally dominant in modified ecosystems. Rather, environmental modification may reduce some forms of ecological resistance and create conditions under which introduced generalist species can establish.

V. MECHANISMS OF POTENTIAL ECOLOGICAL IMPACT

The ecological effects of introduced tilapia can arise through several interacting mechanisms.

5.1 Competition for food

Competition is one of the most frequently proposed mechanisms. When introduced tilapia and native fishes utilize similar food resources, increasing tilapia abundance may increase exploitative competition, particularly where resources are limited.

Competition should nevertheless be demonstrated rather than inferred solely from dietary similarity. Evidence is strongest when dietary overlap is combined with information on resource limitation, growth, recruitment or population responses.

Khan and Panikkar (2009) demonstrated the importance of this distinction. Their trophic model showed that Mozambique tilapia adversely affected indigenous catfishes, whereas Nile tilapia did not produce uniformly negative effects across the fish groups considered. The authors also reported high niche overlap between Nile tilapia and pearl spot.

5.2 Competition for breeding habitats

Tilapias construct nests and may defend spawning territories. Where nesting habitats overlap with those used by indigenous fishes, aggressive territorial behaviour could potentially interfere with spawning activities.

The magnitude of this effect is likely to depend on habitat availability and the spatial distribution of spawning populations. It should therefore be assessed through direct observations of spawning habitats and recruitment rather than assumed from species presence alone.

5.3 Predation on eggs and larvae

Although tilapias are primarily associated with low- to intermediate-trophic feeding, eggs and larvae may become components of their diet under particular conditions. Such interactions could be important for species with vulnerable early life stages.

El-Sayed and Fitzsimmons (2023) reviewed evidence from invaded systems in which competition, egg and larval consumption, and occupation of spawning areas were proposed as mechanisms of impact.

For Indian ecosystems, however, quantitative evidence on the frequency and demographic importance of egg or larval predation remains limited and requires targeted investigation.

5.4 Competition for shelter and space

Juvenile and adult fish often depend on structurally complex habitats for refuge, feeding and reproduction. Dense tilapia populations may alter access to shallow vegetated habitats through territoriality, nest construction and high local abundance.

Such effects could be particularly important in reservoirs where littoral habitat is already constrained by fluctuating water levels.

5.5 Habitat modification

Tilapia feeding and reproductive activities can influence sediment disturbance and benthic habitats. Bioturbation may modify sediment–water interactions, nutrient availability and turbidity. The magnitude of these effects depends on fish density, sediment characteristics and hydrological conditions.

Therefore, habitat modification should be considered a possible ecological mechanism rather than an automatic consequence of tilapia presence.

VI. COMPETITION WITH INDIAN MAJOR CARPS AND OTHER INDIGENOUS FISHES

Indian major carps—including *Catla catla*, *Labeo rohita* and *Cirrhinus mrigala*—are among the most economically important freshwater fishes in India. Several native cyprinids, catfishes and other groups also contribute substantially to inland fisheries.

Potential competition with these species can occur through overlapping food resources, particularly planktonic and periphytic resources. Nevertheless, ecological relationships are not necessarily antagonistic in every ecosystem.

Historical evidence from Indian reservoirs provides an important example. The FAO review of reservoir fisheries reported that tilapia had adversely affected indigenous species in several systems and cited the decline in the catch share of *Cirrhinus reba* in Kabini Reservoir from approximately 70% to 20% between 1980–81 and 1984–85 (FAO, 1997).

This historical observation is important but should be interpreted cautiously because changes in fish catches can reflect several interacting drivers, including fishing effort, stocking, hydrological changes and habitat modification.

Conversely, Khan and Panikkar (2009) found no negative modelled effect of Nile tilapia on Indian major carps in the reservoir examined. This contrasting result demonstrates that species interactions cannot be generalized across all Indian reservoirs.

Accordingly, the appropriate question is not whether tilapia always outcompete Indian major carps, but rather:

Under what ecological and management conditions does tilapia establishment produce measurable demographic or fisheries consequences for indigenous fishes?

This question should guide future research.

VII. EFFECTS ON INDIGENOUS FISH DIVERSITY AND COMMUNITY STRUCTURE

The ecological significance of an invasive species extends beyond direct competition. High abundance of an introduced fish may alter relative species abundance, trophic relationships and community structure.

A shift in community composition can occur through:

- 1) direct competition for food;
- 2) competition for spawning habitats;
- 3) predation on early life stages;
- 4) habitat modification;
- 5) alteration of food-web pathways;
- 6) differential tolerance of environmental degradation; and
- 7) interactions with fisheries exploitation.

However, a reduction in native species abundance following tilapia establishment does not necessarily establish a direct causal relationship.

The 2026 Panam Reservoir study provides an informative example. *O. niloticus* increased from approximately 5% of the catch in 2022 to more than 20% in 2023, becoming the third most abundant species in the reported landings. During the same period, declines were observed in the proportional representation of major and medium carps, minor cyprinids and other native fishes. The study interpreted these concurrent changes as evidence of an emerging community shift, while also emphasizing the need for pathway-focused monitoring and further ecological assessment.

Such evidence is valuable because it documents rapid population expansion; however, concurrent declines should not automatically be attributed exclusively to tilapia. Long-term datasets and controlled analyses are required to separate tilapia effects from other environmental drivers.

VIII. TROPHIC INTERACTIONS AND FOOD-WEB EFFECTS

Food-web interactions provide a mechanistic framework for understanding invasion effects. Introduced species may compete directly with native species, consume organisms that form important prey resources, or modify energy flows among trophic levels.

Tilapias are particularly interesting because they can occupy several trophic positions depending on habitat and resource availability. Their diets may include primary producers, detritus, zooplankton and animal prey.

The modelling study of Khan and Panikkar (2009) illustrates the complexity of these interactions. Their reservoir food-web analysis showed that Mozambique tilapia had an adverse effect on indigenous catfishes, whereas Nile tilapia did not negatively affect the fish groups examined and was associated with a positive modelled interaction with Indian major carps.

These results emphasize that trophic overlap does not necessarily translate into population-level competition. Two species may consume similar resources while resource availability remains sufficient to support both populations.

Recent dietary research further supports the importance of methodological integration. In the Bhima River, Khare et al. (2026) combined conventional stomach-content analysis with DNA metabarcoding and demonstrated that molecular analysis detected a broader range of dietary components than conventional analysis alone. The authors characterized *O. mossambicus* as a flexible zooplanktivorous-omnivorous feeder, potentially increasing trophic overlap with native planktivores.

Future Indian studies should therefore integrate stomach-content analysis, stable-isotope analysis, DNA metabarcoding and population-level data.

IX. TILAPIA IN INDIAN RIVERS

River systems are particularly important for indigenous fish conservation because they contain longitudinal gradients, spawning grounds, nursery habitats and seasonal migration pathways.

9.1 Yamuna River

The Yamuna River has experienced substantial anthropogenic modification, including pollution, flow regulation and habitat alteration. Trivedi et al. (2021) documented Nile tilapia among established exotic fishes in the Yamuna system and highlighted its potential competitive relationship with native fishes.

The presence of an established non-native population in a highly modified river such as the Yamuna is ecologically relevant because environmental degradation may simultaneously affect native fishes and influence the relative success of tolerant non-native species.

Future research should quantify whether tilapia abundance is associated with measurable changes in native fish recruitment, diet, growth and spatial distribution.

9.2 Bhima River

Recent evidence from the Bhima River provides detailed information on the feeding ecology of Mozambique tilapia. Khare et al. (2026) reported a flexible diet involving zooplankton, microinvertebrates and plant-associated resources. The authors suggested that this trophic plasticity may contribute to invasion success and increase the potential for trophic overlap with native planktivorous fishes.

The Bhima case highlights the importance of examining species-specific ecological mechanisms rather than treating all tilapias as functionally identical.

X. TILAPIA IN INDIAN RESERVOIRS

Reservoirs represent particularly important environments for examining fish introductions because they combine features of rivers and lakes and are often directly connected with fisheries enhancement and aquaculture activities.

10.1 Kabini Reservoir

Kabini Reservoir provides one of the historically documented Indian examples of concern regarding tilapia–native fish interactions. FAO (1997) reported a reduction in the catch contribution of *Cirrhinus reba* from approximately 70% to 20% between 1980–81 and 1984–85 in association with tilapia establishment.

Although this historical relationship warrants attention, it should be interpreted as an association rather than definitive proof of a single-species causal effect.

10.2 Panam Reservoir

Panam Reservoir represents one of the most recent documented Indian examples of rapid Nile tilapia establishment. Sajina et al. (2026) reported that *O. niloticus* was associated with an apparent cage-culture escape pathway, became increasingly visible in catches by 2022 and exceeded 20% of total catch by 2023. The study also reported dietary overlap with native fishes and highlighted the importance of trophic plasticity and high reproductive capacity in establishment.

The rapidity of this change demonstrates the importance of early detection. Once the species constitutes a substantial component of the fishery, management becomes more complex because the population has already become integrated into the ecosystem and fishery.

10.3 Food-web evidence from tropical Indian reservoirs

The work of Khan and Panikkar (2009) demonstrates that reservoir-level effects can differ markedly among tilapia species. Their food-web model indicated that Mozambique tilapia adversely affected indigenous catfishes, while Nile tilapia did not negatively affect the fish groups examined.

This finding is particularly important for journal-level interpretation because it demonstrates that a generalized statement such as "tilapia inevitably eliminate native fish" is not supported by the available evidence.

XI. FACTORS DETERMINING THE SEVERITY OF ECOLOGICAL EFFECTS

The ecological consequences of tilapia establishment are likely to depend on several interacting factors.

11.1 Population density

Low-density populations may have limited ecological influence, whereas high-density populations can exert greater pressure on food resources and habitats.

11.2 Resource availability

Where food resources are abundant, dietary overlap may not translate into strong competition. Competition is more likely when resources are limiting.

11.3 Habitat structure

Vegetated littoral zones, shallow spawning habitats and structurally complex areas may influence both tilapia establishment and interactions with native fishes.

11.4 Environmental degradation

Pollution, eutrophication, reduced flow and altered thermal regimes may reduce the abundance of sensitive native species while creating conditions favourable to tolerant species.

11.5 Fishing pressure

Selective fishing may alter community structure independently of invasion. In some circumstances, intensive exploitation of native species may indirectly facilitate the relative increase of tilapia.

11.6 Reservoir age and hydrology

Newly formed or highly regulated reservoirs may undergo substantial ecological transitions. Water-level fluctuations, inflow patterns and habitat availability can influence the establishment and persistence of introduced species.

11.7 Connectivity

Hydrological connectivity determines the potential for dispersal between reservoirs, rivers, canals and aquaculture facilities.

XII. FISHERIES AND SOCIOECONOMIC IMPLICATIONS

The socioeconomic consequences of tilapia establishment are complex because tilapia can simultaneously represent a valuable fishery resource and an ecological management concern.

From an aquaculture perspective, tilapia provide food, income and employment in numerous countries (El-Sayed and Fitzsimmons, 2023). Therefore, ecological concerns should not be interpreted as an argument against tilapia aquaculture as a whole.

The management issue is instead the movement of cultured tilapia into ecosystems where they were not intended to occur.

In capture fisheries, increasing tilapia abundance can have several possible outcomes:

- increased total fish biomass;
- increased availability of a marketable fish;
- changes in species composition;
- reduced representation of preferred native species;
- altered fish prices;
- changes in fishing strategies; and
- changes in fisher income.

El-Sayed and Fitzsimmons (2023) reviewed international examples in which increasing tilapia abundance was associated with reductions in native fish catch and changes in fisher income. However, socioeconomic outcomes are strongly dependent on consumer preferences, local markets, fish prices and the relative value of native species.

For Indian reservoir fisheries, economic assessment should therefore include not only total production but also species-specific value, market demand, fishing effort and livelihood dependence.

XIII. MONITORING AND ASSESSMENT FRAMEWORK

A systematic monitoring programme is essential for detecting ecological changes before introduced populations become difficult to manage.

13.1 Fish-community monitoring

Monitoring should include:

- species composition;
- catch per unit effort (CPUE);
- length-frequency distribution;
- biomass;
- recruitment;
- juvenile abundance;
- reproductive condition;
- spatial distribution; and

- seasonal changes.

13.2 Dietary assessment

A combination of:

- stomach-content analysis,
- stable-isotope analysis,
- DNA metabarcoding, and
- fatty-acid analysis

can provide stronger evidence of trophic relationships than any single method.

13.3 Habitat assessment

Important variables include:

- aquatic vegetation;
- substrate;
- depth;
- dissolved oxygen;
- temperature;
- pH;
- conductivity;
- turbidity;
- nutrient concentrations; and
- hydrological connectivity.

13.4 Genetic monitoring

Environmental DNA (eDNA) and population genetic tools can potentially provide early detection of low-density populations and identify source populations and dispersal pathways.

13.5 Participatory monitoring

Fishers can provide valuable information concerning first appearance, seasonal abundance, changes in catch composition and suspected escape events. The Panam Reservoir study demonstrates the value of Rapid Rural Appraisal and participatory approaches in reconstructing introduction pathways (Sajina et al., 2026).

XIV. MANAGEMENT STRATEGIES

Management should be based on prevention, early detection and ecosystem-specific intervention.

14.1 Prevention

Prevention is generally preferable to attempting eradication after establishment. Aquaculture facilities should employ appropriate containment systems, especially where production units are located near rivers and reservoirs.

Measures may include:

- secure cages and pond outlets;
- flood-resistant infrastructure;
- screened discharge structures;

- emergency escape-response protocols;
- stock inventories;
- responsible transport;
- prohibition of unauthorized release; and
- routine inspection of culture facilities.

14.2 Early detection

Regular monitoring around aquaculture facilities and receiving waters can identify newly established populations.

eDNA surveillance may become particularly useful for detecting low-abundance populations before they become prominent in fisheries catches.

14.3 Targeted removal

Where populations are localized and newly established, targeted removal may be considered. Potential methods include intensified fishing, selective gears and seasonal removal.

However, removal programmes should be evaluated scientifically because incomplete removal may have little long-term effect when reproductive recruitment remains high.

14.4 Fisheries-based control

In some systems, increased exploitation of tilapia may help reduce abundance while generating fishery benefits. Such approaches should be evaluated against biological characteristics, market demand and potential ecological consequences.

14.5 Habitat management

Restoration of native spawning and nursery habitats may improve ecological resistance to invasion by strengthening indigenous fish populations.

14.6 Adaptive management

Management should follow an adaptive cycle:

Detection → Assessment → Intervention → Monitoring → Evaluation → Management adjustment

This approach recognizes that ecological responses may differ among rivers and reservoirs.

XV. RESPONSIBLE TILAPIA AQUACULTURE AND BIOSECURITY

The ecological concerns associated with invasive tilapia should be separated from the legitimate role of tilapia aquaculture in food production.

Tilapia farming can be conducted responsibly when production systems are appropriately designed and managed to minimize escape risk. Biosecurity should be considered particularly important in:

- cage culture;
- flood-prone ponds;
- farms connected to rivers;
- reservoirs with valuable indigenous fisheries; and
- facilities located near biodiversity-sensitive habitats.

The Panam Reservoir case demonstrates why cage-culture operations require careful pathway assessment. The reported escape-associated establishment of Nile tilapia illustrates how a localized production event can potentially develop into a reservoir-scale fisheries issue within several years.

Responsible aquaculture should therefore incorporate risk assessment before stocking, appropriate containment during production and contingency plans for extreme weather and infrastructure failure.

XVI. CONCLUSION

Tilapias, particularly *Oreochromis niloticus* and *O. mossambicus*, have become established in several Indian freshwater environments and warrant continued ecological and fisheries monitoring. Their broad environmental tolerance, reproductive capacity, trophic flexibility and ability to exploit modified habitats provide biological characteristics that can facilitate establishment outside their native ranges.

Available evidence indicates that tilapia can interact with indigenous fishes through food-resource competition, habitat use, trophic overlap and potentially through effects on spawning and recruitment. Historical observations from Indian reservoirs, recent evidence from the Yamuna and Bhima rivers, and the rapid establishment of Nile tilapia in Panam Reservoir collectively demonstrate that introduced tilapias can become important components of Indian freshwater fish communities (FAO, 1997; Trivedi et al., 2021; Khare et al., 2026; Sajina et al., 2026).

Nevertheless, the ecological effects are context dependent. Evidence from food-web modelling demonstrates that different tilapia species may produce different effects within the same ecosystem and that negative effects on native fishes should not be assumed solely from species presence (Khan and Panikkar, 2009). Environmental degradation, hydrological alteration, fishing pressure, habitat modification and other introduced species may also contribute to observed changes in fish-community structure.

The principal management priority should therefore be prevention of further unintended introductions and rapid detection of newly established populations. Aquaculture biosecurity, particularly in cage and flood-prone systems, is central to this strategy. Where tilapia populations are already established, management should be ecosystem-specific and based on measurable ecological objectives.

Ultimately, the challenge is not simply the presence of tilapia but the interaction between introduced populations, environmental change, aquaculture pathways, native fish communities and human fisheries. A combination of long-term ecological monitoring, modern molecular tools, trophic studies, fisheries assessment and participatory management will be required to determine where tilapia establishment represents a substantial ecological risk and where its effects remain limited.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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