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Literature review

# Technical factors of water quality and sediment management in shrimp-tilapia polyculture in ponds

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## ABSTRACT

The polyculture of tilapia fish and shrimp is one of the mitigation techniques to reduce sanitary impact and effluents in shrimp farms. It mostly aims to increase production and control water quality of effluents. Some cases of success have reported the control of certain diseases and the improvement of soil quality in earthen ponds. This review analyzes the benefits obtained in terms of water quality, sediments, environment, production increase, and improvement of zootechnical parameters of shrimp polycultured with tilapia fish. Shrimp-tilapia polycultures can contribute with a positive effect to water quality and sediments from ponds and effluents of farms; this depends on density and environment conditions where polycultures are developed. However, they must be adapted, and their functionality and commercial profitability must be proven at small and large scales.

**Keywords**: Aquaculture; benefits; co-cultures; environment; mitigation (Source: CAB).

## RESUMEN

El policultivo de camarón-tilapia es una de las estrategias de mitigación para los impactos sanitarios y los efluentes en las granjas camaroneras. Su finalidad principal es incrementar la producción y controlar la calidad del agua de sus efluentes. En casos de éxito se controlaron algunas enfermedades y mejoró la calidad del suelo en estanques de tierra. En esta revisión, se analizan los beneficios que se obtienen en la calidad del agua, sedimento, medio ambiente, incremento del rendimiento y el mejoramiento de los parámetros zootécnicos de camarones co-cultivados con tilapia. Los policultivos de camarón-tilapia pueden contribuir con un efecto positivo sobre la calidad del agua y sedimentos de los estanques y efluentes de las granjas de cultivo, lo cual depende de las condiciones de densidad y ambiente donde se desarrollan. Sin embargo, se requiere adaptar y demostrar su funcionalidad y rentabilidad comercial a pequeña escala e industrialmente.

**Palabras clave**: Acuicultura; beneficios; co-cultivos; medioambiente; mitigación (Fuente CAB).

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# INTRODUCTION

The development of rural aquaculture has been characterized by its growth in recent decades and strongly emerges as a guarantor of food security and the improvement of economy in low-income populations. This has contributed to local economic development. Among the characteristics that contribute to rural development is the fact that around 90% of the producers are small-scale. Aquaculture provides employment to approximately 19.3 million people worldwide (1), and it represents a key source for the economy and development of Southeast Asia, Africa, and Latin America. This allows producers to prevent their exclusion from the business and thus the market is not controlled by industrial-scale producers.

Cultures have been documented to deeply affect ecosystems. Over time, several strategies for integrated aquaculture have been proposed as part of the solution (2). The characteristics of effluents from shrimp cultures and their effects are widely known. Among them are the increase in salinity, suspended solids, organic particles, chlorophyll a, and bacteria in coastal ecosystems, as well as a reduction in dissolved oxygen (DO) and transparency (3).

Shrimp polyculture is an old practice that might have evolved from the first extensive shrimp systems in which fish species as milkfish (*Chanos chanos*) and mullet (*Mugil spp*.) were incidental or introduced and intentionally harvested as additional cultures to shrimp (4). A major development might have involved the introduction of fish into red algae (*Gracilaria edulis* and *Gracilaria changii*) tanks as an additional source of income (5). The research on shrimp polyculture with several fish and bivalves (6,7) has been implemented to increase production and control water quality. These research works and cultural practices are mainly based on extensive and semi-intensive systems. Few attempts have been made to polyculture shrimp at an intensive level as with monocultures (8). The aim of this work is to review the basic notions of pond ecology, water quality, sediments, technology, and environment of the shrimp-tilapia polyculture.

## Integrated aquaculture or polycultures

The definitions of integrated aquaculture and polycultures are well known. Essentially, the refer to an aquaculture production system in which the waste produced by a subsystem is used by another one linked, resulting in a greater overall efficacy of the system. Subsystems can be aquatic, fish, agricultural, and livestock species or belong to other human activities. The goal of integrated production is to create balanced systems for environmental sustainability (biomitigation), economic stability (product diversification and risk reduction), and social acceptability (better practices) (9).

Polycultures are also known as multitrophic aquaculture, co-culture, or simply integrated aquaculture (9). There are at least three general types of polyculture: direct, in cage-cum-pond, and sequential (10). The first refers to two or more mixed species in the same pond or aquaculture unit without partitioning; that is, physical contact between species is possible. Cage-cum-pond polyculture is similar to the direct one in that different species are cultured together in the same tank or pond but one or more are caged, limiting their space and physical contact with the main organism (11). As in the first type, additional space is not necessary and control over species culture is better.

Sequential polyculture involves integrated aquaculture where the main and subordinate species are separated by different units. In it, the effluent flows from ponds of the main species into the culture units of the subordinate species. In some of these models, water is discharged into receptor ecosystems, while in others, it is recirculated. The secondary species thrives in effluents from ponds of the main species as it benefits from non-consumed food, organic matter, and other nutrients. This process improves the quality of discharged water, so it can be reused, and lowers the environmental impact of the process (12).

Within integrated practices, the rice-fish aquaculture is probably one of the oldest. It has been mostly applied in Asia and has recently extended to other regions (13). This aquacultural strategy has been long practiced in brackishwater ponds with extensive and semi-intensive shrimp, fish, and agricultural plants (rice) systems. Nowadays, it is principally found in China, Indonesia, India, Philippines, Taiwan, Thailand, Japan, Vietnam, and, more recently, Bangladesh (14). A great deal of research and experience on integrated aquaculture in brackish water has been gathered in Southeast Asian countries. However, there is scarce information on the socioeconomic performance of such systems, with the exception of the integrated culture of rice and shrimp.

Among polycultures in tropical coastal ponds, species historically cultured in tide-fed ponds are particularly relevant. Their production reflects the composition of species in incoming water. These ponds are often shallow water bodies along bays and estuaries and their size varies from a few to over 100 ha (15).

## Ecology of ponds with shrimp-tilapia polyculture

The shrimp-tilapia polyculture is known to reduce nitrogen waste, which turns into toxic metabolites. Tilapia can feed on and assimilate most of the waste generated by shrimp culture in any known modality. In polyculture systems, waste is assimilated through the food web in the pond ecosystem created by the cultured organisms, the natural sediment, and water biota. Evidence shows that the diversity of species in a specific environment affects a number of ecosystem processes, including productivity, decomposition, and nutrient cycle (16).

Sea shrimp are benthic, spend most of their life in contact with the seabed, and possess a wide range of feeding habits in natural systems. These crustaceans have been described as omnivore scavengers, opportunistic omnivores, carnivores, and predators that feed on waste. They can consume detritus aggregates, including bacteria and meiofauna, protozoa, microalgae, zooplankton, and macrobenthos, among others (17). Shrimp in intensive culture ponds also feed from large sources from small suspended and sedimentable solids (18).

Tilapia is one of the few domesticated fish species that feed on natural sources of low trophic level, as detritus and plankton. Since they can grow in saline water after an adequate acclimation, tilapia fish are the most indicated for a shrimp-fish polyculture system.

The wide variety of elements found in tilapia stomach shows these fish have no selective diet. Apparently, each species is able to use several protein sources as food. Tilapia fish in aquacultural systems feed selectively on large plankton, particularly zooplankton. This results in decreased predation pressure on small phytoplankton, leading to a high productivity. The fish take full advantage of water nutrients since there are large areas of absorption surface and a low precipitation index (19). When they swim around in the bottom over the sediment, tilapia indirectly improve water movement and nutrient cycle. On the other hand, the energy excreted by the fish works as slow, uniform fertilization to maintain a constant and optimal phytoplankton biomass instead of a dramatic variation; organic detritus is filtered so a good water quality is preserved (20).

## Water and sediment quality in polyculture ponds

The nutrient cycle in shallow water ecosystems is affected by the interaction between sediments and water. The microbial community plays a key role in the transformation of organic matter deposited on the sediment bottom. The matter becomes a source of remineralized nutrients for plankton growth. The deposition of detritus loads, resulting from the plankton precipitated to the bottom and other organisms, creates eutrophic waters. The tilapia monoculture can produce a significant deposition of excess organic matter and a better water quality as shrimp do not use the upper water column, promoting plankton instability (20).

Most of the shrimp ponds are currently oxygenated introducing air using paddled devices and propeller aspirators placed around the pond borders. This equipment produces circulation in the whole pond and directs non-consumed food, shrimp feces, and detritus to the center of the pond where they accumulate in the sediment. The latter is fast turned into anaerobic substrate, resulting in reduced nitrate, iron, sulfate, and other compounds (21). It has been proven that compounds as ammonium, ferric iron, and hydrogen sulfide are released into the water column (22). Shrimp are predominantly epibenthic and their health can be directly damaged by low oxygen levels and compounds released during decomposition processes in the sediment. It is hypothesized that poor-quality sediment severely hampers the semi-intensive and intensive shrimp production (23).

Tilapia as a secondary species in shrimp cultures has been suggested to promote (a) *Chlorella sp*. as major alga, (b) feed on organic waste, (c) sediment bioturbation, and (d) production of natural antimicrobials (22).

These benefits have been obtained in the three co-culture systems known (direct, cage-cum-pond, and integrated co-culture). Some authors summarize the advantages as ecological impact and improvements in yield and water quality (24). More specifically, under certain conditions, nutrient retention is promoted while nitrogen produced by the cultures is reduced (1,28). When cultured with shrimp, tilapia is key to reduce phytoplankton biomass and promotes bioremediation by microalgae (25). After carbon, nitrogen is the most important nutrient for microalgae, and it is added as nitrate ($NO_3^-$) or ammonium ($NH_4^+$) (30). Algae use $NO_3^-$ and convert it into more useful products, as proteins, when consumed by fish and shrimp (Table 1) (26).

As a monoculture, tilapia can produce a significant deposition of excess organic matter and reduce water quality while shrimp do not use the upper water column, favoring plankton stability (23). In open systems, microalgae are susceptible to grazing by some zooplankton groups, such as cladocerans, rotifers, and nematodes, which can be used by tilapia (25). Shrimp feed on organic detritus produced by the herbaceous vegetation in marshes; phytoplankton and benthic algae are the major food sources (26).

Two direct inhibitory effects of tilapia (*V. harveyi*) on shrimp are the production of mucus on the surface and other metabolites and microflora associated to tilapia culture. The same positive effect has been reported in shrimp with specific antibacterial activity against *V. harveyi* (27).

Tilapia can filter phytoplankton and organic waste. This can eventually affect the physiological state of shrimp and may turn into a potential pollutant in environments that receive farm effluents (28).

Juarez-Rosales et al. (2020) studied the water quality of tilapia-white shrimp (*P. vannamei*) polyculture ponds. They identified that the high-density addition of tilapia can improve productivity and nutrient use (29). In addition, there was a trend towards a greater nutrient concentration in water of shrimp monoculture ponds during dry season, along with a higher amount of DO and biochemical oxygen demand in five days ($BOD_5$) (Table 1).

The concentration of ammonia ($NH_3^+$) in the culture towards the last weeks of dry season increased, up to 0.306 mg $l^{-1}$, in white shrimp-Nile tilapia polycultures. The increase was 0.293 mg $l^{-1}$ in monocultures, the averages being 0.287±0.4 mg $l^{-1}$ and 0.227±0.1 $mg^{-1}$, respectively (29). These concentrations are different with respect to the rain cycle when they were 0.406 ± 0.2 mg $l^{-1}$ in monocultures and 0.376 ± 0.1 mg $l^{-1}$ in polycultures (Table 1). They are evidently higher and inverse, so it is concluded there is a marked decrease in the records of polycultures.

When $NH_4^+$ concentrations were compared, significant differences were observed in similar shrimp monoculture systems (8). This could be attributed to the fact that $NH_4^+$ levels tend to increase as a result of residue accumulation while feeding rates are higher in the crop cycle (8). Boyd (30) identifies an optimal $NH_4^+$ range of 0.2–2.0 mg $l^{-1}$ for shrimp ponds. In addition, $NH_3^+ > 1.93$ mg $l^{-1}$ can lead to toxicity complications when the pH is above 8.5. The acceptable concentration of toxic $NH_3^+$ for penaeids, as shrimp, is maximum 2 mg $l^{-1}$, along with a good growth of *L. vannamei* (0.2 mg $l^{-1}$) (30). High $NH_3^+$ concentrations affect shrimp growth, shedding, oxygen consumption, and $NH_4^+$ excretion (31).

The concentration of major and minor nutrients in sediments of ponds corresponding to shrimp monocultures and tilapia-shrimp polycultures increases throughout the production cycle as the texture of the sediment (sand, silt, and clay) is modified (29). The major nutrients are nitrogen, phosphorus, and potassium while the minor ones are calcium, magnesium, and sodium. The concentration of organic matter found in sediments of polyculture ponds is within that reported of shrimp monoculture in brackishwater ponds (29). Larger amounts of organic matter have been reported in sediments of shrimp-tilapia polycultures due to the greater contribution of food and the higher organism density vs monocultures. The accumulation of organic matter is integrated mostly by exogenous contributions as eroded soil, non-consumed food, feces, plankton, and dead microorganisms (29).

Still, tilapia fish have been reported to decrease nitrogen and phosphorus concentrations by sediment bioturbation. They also increase oxygen concentration in sediments (32). After studying shrimp-tilapia polycultures for two seasons of the year, some authors have concluded that the sediment of shrimp monoculture ponds absorbed a large amount of total phosphorus (TP) during wet season, as compared against total nitrogen (TN); the opposite occurs in tilapia polycultures (31). This agrees with the findings in sediments of shrimp ponds (33).

**Table 1**. Variables of water quality in shrimp monoculture and shrimp-tilapia polyculture.

| T °C | DO (mg $l^{-1}$) | pH | Salinity (g $l^{-1}$) | TA (mg $l^{-1}$) | TAN (mg $l^{-1}$) | $NO_3$ (mg $l^{-1}$) | $NO_2$ (mg $l^{-1}$) | TN (mg $l^{-1}$) | TP (mg $l^{-1}$) | TSS (mg $l^{-1}$) | Ref |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 30.9 ±3.07 | 6.47 ±1.12 | NA | NA | 155.4 ±21.1 | NA | 2.54 ±1.54 | NA | NA | 2.79 ±1.26 | NA | (34) |
| 28.5 ±0.2 | 7.7 ±0.12 | 7.8 ±0.1 | 5.0 ±0.5 | ND | 0.42 ±0.0 | 0.188 ±0.07 | 0.03 ±0.002 | NA | NA | NA | (35) |
| 29.2 ±3.8 | 5.4 ±0.9 | 8.0 ±0.4 | 11.2 ±4.5 | 69.5 ±7.6 | 0.43 ±0.2 | 1.4 ±0.10 | 0.18 ±0.01 | NA | 0.29 ±1.0 | 66.1 ±7.0 | (24) |

T: Temperature; DO: Dissolved oxygen; TA: Total Alkalinity; TAN, total ammonia nitrogen; NO2, nitrites; NO3, ammonium; TN, total nitrogen; TP, total phosphorus; BOD5, biochemical oxygen demand in five days; TSS, total suspended solids; NA, non-available.

## Technical aspects of shrimp-tilapia polyculture

The polyculture is based on the principle that each species placed in the culture system has its own ecological and trophic niche. Therefore, food resources and the available space are more thoroughly used than in a monoculture. In some cases, a species improves food availability for others; that is, tilapia can increase the production and improve the feed conversion ratio (FCR) of shrimp (35). Several nutrients in the system come from food that was not assimilated by the fish, which indicates shrimp may take them and use them to supplement their diet and increase the total yield per unit of area (36). Shrimp-tilapia polycultures not only promote the yield and survival of the main species but also result in the production of tilapia as a secondary benefit (34).

Given that food accounts for over 60% of the production costs in most of the species, reducing costs is important to increase efficiency and profitability (20). Then, the production cost of a polyculture system is lower when compared against a monoculture system, which allows for cost savings. Research on polycultures has revealed that plankton bloom and pH are more stable in these ecosystems. This can be attributed to the bioturbation that favors the slow but steady release of nutrients into the water.

It must be considered that the majority of studies on the interaction tilapia-shrimp have been conducted in controlled systems. It has been found that the total fish and shrimp production is higher in polycultures than in monocultures (35). However, their diet is more balanced and FCR is higher in monoculture earth ponds. Overall, general FCR is higher in clear water systems than in earth ponds employed for monocultures and polycultures (36).

Studies have found the difference in tilapia survival is smaller in monocultures (84–87.6%) and polycultures (91.2–100%) in earth ponds (24). Natural earth ponds with high-quality water and low salinity allow for the sustenance of an increasingly dense tilapia population (4 org/$m^2$) unlike systems or ponds that lack substrate (1.2 org/$m^2$) at the bottom (fiberglass or concrete tanks) (Table 2) (24). In general, the tilapia-shrimp polyculture poses more technical advantages in extensive and semi-extensive cultures in commercial terms.

## Environmental aspects of shrimp-tilapia polyculture

Research on the environmental effects of shrimp-tilapia polycultures has concluded that, under certain conditions, the polycultures promote nutrient retention. In addition, the amount of nitrogen generated by aquacultural cultures is dramatically decreased (24).

It has been documented that this type of culture system favors the control of plankton bloom and reduces the prevalence of some bacteria. In consequence, the survival indices are improved (39). In contrast, reports indicate that the shrimp-tilapia strategy doubles $NH_3^+$ discharge (27).

From an economic standpoint, polycultures can demand a great initial investment because of the infrastructure, ventilation, feed, and effort. Still, this investment depends on the type, intensification, and design of the system.

**Table 2**. Growth yield of shrimp in co-culture with tilapia at different densities and systems (mean ± SD).

| SP | DS | DT | Final weight (g/ind.) | Performance (tons/he) | Survival (%) | FCR | SGR (g/day) | Cultivation system | Ref |
|---|---|---|---|---|---|---|---|---|---|
| Shrimp-tilapia (*P.ch. -O.m.*) | 7.5 | | 10.4 ±0.1 | 0.337 ±00.0 | 65.5 ±21.70 | | | Tanks - closed; intensive system | (37) |
| Shrimp-tilapia (*P.v.-O.n.*) | 20 | 4 | 9.7 ±0.1 | | 100 | 1.73 ±0.01 | 0.240 ±0.01 | Sequential tank system | (36) |
| Shrimp-tilapia (*P.v.-O.n.*) | 3 | 0.5 | 14.01 ±0.5 | 222.64 ±34.7 | 34.41 ±4.9 | 2.27 ±0.04 | | Earthen ponds; Opened | (38) |
| Shrimp-tilapia (*P.m.-O.m.*) | 40 | 3 | 13.35 ±0.4 | | 84.7 ±2.3 | 1.27 ±0.04 | 0.213 ±0.01 | Closed tanks | (39) |
| Shrimp-tilapia (*P.v.-O.n.*) | 10 | 4 | 14.3 ±0.2 | 1.0 ±7.1 | 75.2 ±4.6 | 2.36 ±0.10 | 3.2 ±0.54 | Earthen ponds; Opened | (24) |

SP: Species in Polyculture; DS: Densities (Shrimp/m$^2$); DT: Densities (tilapia/m$^2$); *P.m., Penaeus monodom; O. m., Oreochromis mossambicus; P. ch., Penaeus chinensis; O. n., Oreochromis niloticus; P.v.,Penaeus vannamei.*

The introduction of a secondary species is risky since it suggests the possibility of introducing pathogens into the culture system (34). Furthermore, there are some feed difficulties in the integration of tilapia and shrimp; the former can feed on the rich protein supply given to shrimp as they suppress zooplankton (32). This can reduce the primary production rate in ponds, affecting shrimp growth (32).

It has been found that the shrimp-tilapia strategy doubles the $NH_4^+$ discharge in mixed shrimp-tilapia cultures (27). In aquaculture, the toxicity of excreted nitrogen compounds is the most limiting parameter since oxygen levels are kept adequately (40). The greatest source of nitrogen compounds in culture systems comes from the metabolism of proteins contained in food (40). On the other hand, $NH_3^+$ is the main byproduct of the catabolism of fish and shrimp proteins (31). Then, toxicity problems may arise in all types of culture systems. Indeed, effluents from aquaculture farms with shrimp-tilapia polycultures synergically affect water quality under the natural conditions of the hydrology in lagoon-estuarine systems where they establish. There is a loss of vegetable cover due to the use of ground and the loss of biodiversity.

Among the mitigation techniques against the impact of effluents from shrimp farms are the use of mangroves and halophiles as biofilters (41) and sedimentation ponds to reduce suspended solids (29), the elimination of or reduction in water refill along the cultivation period (28), the use of wetlands (28) and the biological removal of organic and inorganic matter through filtering organisms (42). Other alternatives to remove nutrients are the use of micro- and macroalgae (42), the implementation of combined mollusks, macroalgae, and sedimentation (29), and polyculture (29). Still, because of operation issues and costs, it has been found that remediation systems have more applications in commercial farms.

In conclusion, shrimp-tilapia polycultures can generate a positive effect in water quality and sediments of ponds and effluents from farms. This depends on the density and environmental conditions where they are developed.

Within culture ponds, the reduction in concentration, along with phosphorus when incorporating tilapia as secondary species, improves food conversion and increases shrimp growth and thus that of biomass. This can stem from the greater availability of living food with a better quality and the metabolization from bioturbation, all triggered by tilapia in the bottom of ponds.

Finally, it is necessary to fully understand the role tilapia plays in the process as well as the culture protocol used in terms of amount and quality of the food provided. It is also important to thoroughly identify the water retention time and refill in ponds, along with the ventilation type and its efficiency and periodicity, among others.

## Conflict of interests

The authors of this work declare that there is no conflict of interest


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