Guppy Fish (*Poecilia reticulata*) and its Use in Scientific Research - a Short Narrative Review

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Abstract
For many years, the Guppy fish (*Poecilia reticulata*) has been a new model organism in the family of laboratory animals used especially in the field of behavioural ecology and evolutionary biology. This short narrative review is trying to summarize some of the guppy fish uses, from its early discovery and its use as an aquarium pet fish to modern specialized use as a laboratory animal in various applications. This review-type study highlights important advances in our knowledge of life-history evolution under diverse pressure from predators and partner selection, particularly the complex interaction between the use of males as ornamental fish and the use of females for their reproductive capabilities. The paper also discusses the specie's significance in genomic and ecotoxicology studies, where its short period of time between new generations and environmental sensitivity, can offer precious information for tracking aquatic health status. This overview shows the guppy fish continued status as a flexible tool for answering basic biological issues by combining these several research streams.

Keywords: aquarium fish, ecotoxicology, laboratory animals, model organism, *Poecilia reticulata*.

1. Introduction

The diversity of aquatic vertebrates employed in scientific experimentation has significantly broadened the spectrum of methodological options available to contemporary biological inquiry. While the Japanese medaka (*Oryzias latipes*) and the zebrafish (*Danio rerio*) remain the predominant teleost laboratory models [1], there is an increasing emphasis on other small freshwater species that offer complementary insights into ecology, reproduction, and ethology. Among these, the guppy (*Poecilia reticulata* Peters, 1859) has progressively emerged as a highly adaptable and manageable species for experimental purposes [2].

Native to northeastern South America and parts of the Caribbean, guppies were initially introduced globally as ornamental aquarium fish due to their hardiness, vibrant coloration, and rapid reproductive rate. Subsequently, their integration into laboratory settings was facilitated by these same attributes.

The biological profile of the guppy—a small tropical poeciliid—is characterized by internal fertilization, live-bearing reproduction (viviparity), short gestation periods, early sexual maturation, and continuous brood production. These traits permit the maintenance of stable breeding colonies with minimal infrastructure and relatively low maintenance costs [3]. The species is particularly conducive to research on mate choice, reproductive allocation, and sexual

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selection, owing to its pronounced sexual dimorphism: females are larger and highly fecund, while males possess ornate, vivid pigmentation.

Historically, much of the scientific prominence of *P. reticulata* derived from evolutionary field studies conducted in Trinidad. There, naturally fragmented watersheds with fluctuating predation pressures provided ideal conditions for observing rapid adaptive divergence [4]. In their natural habitat, the guppies have camouflage coloration, dull colors to protect themselves from predators. However, due to their introduction into aquariums, over the years, aquarium enthusiasts, and especially those for guppies, have intensified their selection so that, at the moment, there are a very large number of colors and fin shapes as seen in Figure 1.

Also in Figure 1, those two females (on the left and on the right side of the pictures) lack pigments on their body, and they have only a fragment of their tail with light orange pigments.

Figure 1. Different colours and body types in guppy males
(Imagine generated with the help of AI program – Google Gemini®)

These foundational investigations established the guppy as one of the most valuable vertebrate species for studying phenotypic plasticity, predator-mediated selection, and life-history evolution. However, within the last decade, guppy research has progressively moved beyond classical ecology into laboratory-based disciplines such as aquatic bio-monitoring, endocrine toxicity, reproductive physiology, comparative genomics, and the biology of aging [5].

The extensive scientific utility of the guppy can be attributed to a synergy of practical and biological advantages. They are cost-effective, easily bred, tolerant of moderate environmental fluctuations, socially expressive, and highly responsive to external stressors. Notably, numerous physiological and behavioral parameters—including courtship displays, fecundity, and locomotor activity, shoaling behavior, pigmentation, and stress responses—can be visually quantified with minimally invasive intervention [6]. This renders the species suitable for both exploratory laboratory screening and multi-generational (longitudinal) studies.

Simultaneously, the increasing utilization of guppies necessitates rigorous methodological and ethical considerations. As vertebrates, these fish are protected under European research legislation; furthermore, husbandry variables such as water quality, social density, handling stress, and nutritional regimes directly impact scientific reproducibility [7]. Unlike the zebrafish, husbandry protocols specific to the guppy have been less comprehensively synthesized in the literature. Consequently, this analysis aims not only to summarize the primary scientific applications of *P. reticulata* but also to situate these applications within the broader context of laboratory animal science, welfare management, and ethical refinement [8].

2. Materials and methods

A systematic literature search was conducted across multiple electronic databases such as: MEDLINE (PubMed), Google Scholar, Web of Science, MDPI and ResearchGate.
For the search strategies were used specific Boolean operators and keywords such as: guppy, aquarium fish, ecotoxicology, laboratory animals, model organism, *Poecilia reticulata* and guppy fish.
To ensure contemporary relevance, the scope was restricted to peer-reviewed literature published in the last decade. While the search was inclusive of both abstract and full-text, articles without linguistic restrictions, the initial query yielded over 3000 results. Following a rigorous screening process, 120 papers were shortlisted, of which 52 were ultimately selected for inclusion in this study.
The findings were subsequently synthesized into a presentation poster, formatted in strict accordance with conference guidelines for on-site delivery.

3. Housing, Husbandry, Welfare, and the Laboratory Regulatory Framework

The reliable scientific utilization of *Poecilia reticulata* fundamentally depends upon stable and species-appropriate husbandry.
In aquatic laboratory models, *housing* is not merely a logistical requirement but a primary determinant of welfare, endocrine homeostasis, reproductive consistency, and behavioral validity. Subtle fluctuations in temperature, dissolved oxygen, pH, social composition, or feeding frequency can induce measurable alterations in stress physiology, thereby compromising experimental outcomes [9].
As a tropical freshwater teleost, the guppy is ideally maintained at temperatures ranging from 24 to 28°C, pH values between 6.8 and 7.8, dissolved oxygen levels exceeding 5 mg/L, and negligible concentrations of ammonia or nitrites.
Light-dark photoperiods of 12:12 hours or 14:10 hours are commonly employed to support circadian stability and reproductive activity. Guppies may be housed in standalone aquaria or in recirculating rack systems equipped with biological and mechanical filtration [10].
Recirculating systems are generally preferred in research institutions, as they offer superior standardization of water chemistry and reduce labor-intensive maintenance.
Given that guppies are active, shoaling fish, population density must be meticulously controlled. Overcrowding not only deteriorates water quality but also exacerbates chronic social stress and competition. In mixed-sex colonies, excessive male density can result in persistent courtship harassment, which may impair female welfare and diminish reproductive capacity. Consequently, sex ratios and group composition should be regarded as experimental variables rather than mere husbandry details [11].
Daily husbandry routines include the visual inspection of swimming activity, feeding behavior, body condition, and mortality, alongside regular monitoring of filtration efficiency. Weekly water quality analysis and partial water changes remain essential, even within recirculating systems. As guppies are viviparous (live-bearing) species, breeding colonies often require dedicated nursery compartments to prevent juvenile predation and to generate synchronized age cohorts.
Handling constitutes another critical welfare factor. Net pursuit induces acute stress responses, characterized by elevated cortisol levels and transient anorexia. Therefore, fish transfer should be minimized and conducted using soft nets or water-filled containers. Prior to behavioral or toxicological assays, acclimatization periods are necessary to eliminate handling artifacts. Should invasive procedures be required, immersion anesthesia with buffered tricaine methanesulfonate (MS-222) is considered the gold standard [12].
From an ethical perspective, the guppy falls under the purview of European Directive 2010/63/EU, which regulates all vertebrate animals used for scientific purposes within the European Union [13].
This legislation mandates project authorization, trained personnel, severity classification, daily welfare monitoring, and the minimization of pain, suffering, distress, and lasting harm [14]. Complementary recommendations issued by FELASA emphasize harmonized aquatic husbandry, biosecurity, quarantine management, environmental consistency, and welfare-orientated staff training [15].
The 3Rs principle (Replacement, Reduction, and Refinement) is particularly salient in guppy research:

Replacement is achieved when guppies substitute for higher-order vertebrates in preliminary reproductive or toxicological studies [16].
Reduction is facilitated by their high fecundity, allowing for robust sample sizes derived from a relatively small number of breeding adults [17].
Refinement encompasses social housing, environmental enrichment, reduced handling, and the employment of non-invasive behavioral endpoints [18].

It is imperative to note that optimizing guppy welfare is not merely an ethical obligation; it is a scientific necessity, as stress-related endocrine disruption can directly alter pigmentation, mating behavior, fecundity, and sensitivity to contaminants [19].
As described, guppies are fish that can be easily raised in laboratory setups and some advantages and disadvantages are stated below, in Table 1.

Table 1. Main advantages and disadvantages of Guppies (*Poecilia reticulata*) as a laboratory model

Advantages	Disadvantages
Small body size and low maintenance cost	Lower molecular standardization than zebrafish
Rapid maturation and high reproductive output	Fewer transgenic resources available
Live-bearing reproduction allows direct juvenile observation	Behavioral results can be socially variable
Strong sexual dimorphism useful for mate choice studies	Less internationally harmonized protocols
Hardy and adaptable under laboratory conditions	Husbandry often underestimated due to perceived hardiness
Suitable for multigenerational experiments	Embryological accessibility limited

4. Guppies in Ecotoxicology

Ecotoxicology constitutes one of the most rapidly expanding disciplines in which *Poecilia reticulata* has been employed. The escalating contamination of freshwater ecosystems by pesticides, heavy metals, endocrine disruptors, pharmaceutical residues, detergents, and micro plastics has necessitated the development of sensitive vertebrate models capable of detecting not only lethal toxicity but also subtle, chronic biological perturbations [20].
Within this framework, the guppy offers several distinct advantages: they exhibit marked sensitivity to environmental stressors, are amenable to maintenance in replicated experimental cohorts, and facilitate the evaluation of behavioral, reproductive, histological, and biochemical endpoints. Due to their continuous interaction with the water column through respiration, osmoregulation, and foraging, guppies are readily exposed to dissolved toxicants and suspended particulates [21].
Contemporary ecotoxicology has progressively transitioned from fundamental LD50 mortality assays toward the utilization of sub lethal biomarkers, a domain in which guppies are particularly advantageous. Even trace concentrations of pollutants can elicit quantifiable alterations in locomotor activity [22], shoaling cohesion, courtship intensity, feeding latency, respiratory frequency, and predator avoidance [23].
Investigations into heavy metal exposure—specifically involving cadmium, lead, mercury, chromium, and copper—have documented branchial (gill) lesions, hepatic degeneration, diminished antioxidant capacity, and impaired brood production in *P. reticulata*. Notably, many of these physiological alterations manifest at concentrations insufficient to induce acute mortality, thereby underscoring the sensitivity of the model for chronic environmental risk assessment [24].
Endocrine-disrupting compounds represent another significant area of inquiry. Plasticizers, synthetic estrogens, detergent surfactants, and pharmaceutical residues have been shown to alter male gonopodium development, the expression of sexual ornamentation, sperm motility, mating frequency, brood size, and gestation intervals [25].
Given that reproduction in guppies is highly conspicuous and exhibits pronounced sexual dimorphism, such endpoints can be quantified

with relative ease, providing a pragmatic bridge between molecular endocrine disruption and ecological reproductive consequences [26].

Recent years have also witnessed the increased deployment of guppies in micro plastic exposure experiments.

The chronic ingestion of suspended micro particles has been associated with oxidative stress, stunted growth, altered feeding efficiency, and developmental shifts in juvenile stages. As active visual foragers, guppies readily ingest particles that mimic the dimensions of their natural prey, rendering them effective models for studying particulate contamination [27].

A further substantive merit of the guppy model lies in its application within integrated bio monitoring frameworks. Rather than evaluating isolated compounds, certain studies expose guppies to complex wastewater effluents or contaminated field-collected water samples, thereby facilitating the simulation of realistic, multifactorial pollution scenarios [28].

In these instances, alterations in reproductive output, pigmentation, oxidative enzymes, and social behavior serve as viable sentinel indicators. While the standardization of assays remains less harmonized than that of the zebrafish, cumulative evidence confirms that *P. reticulata* occupies an increasingly critical niche in contemporary ecotoxicology, owing to its synthesis of robustness, sensitivity, and reproductive tractability [29, 30].

5. Guppies in Behavioral Ecology and Evolutionary Biology

Behavioral ecology and evolutionary biology constitute the historical scientific core of guppy research. Few vertebrate species have contributed as profoundly to the empirical understanding of sexual selection, life-history trade-offs, predator-mediated adaptation, and collective behavior as *Poecilia reticulata*. This significance is derived from the species' short generation time, pronounced phenotypic plasticity, and robust responsiveness to ecological selective pressures [31].

The guppy populations of Trinidad represent perhaps the most celebrated natural experiment in vertebrate evolutionary biology. River systems fragmented by waterfalls create low-predation upstream habitats and high-predation downstream habitats. Across multiple independent watersheds, these contrasting environments repeatedly generate parallel life-history divergences. High-predation guppies attain maturity earlier, produce more numerous but smaller offspring, form tighter shoals, and exhibit reduced male ornamentation [32]. Conversely, low-predation populations mature later, produce fewer but larger offspring, and display more conspicuous sexual coloration. Such repeated adaptive divergence provides one of the clearest demonstrations of predictable evolution driven by natural selection [33].

Sexual selection represents the most emblematic facet of guppy biology. Male guppies exhibit extraordinary variation in orange, black, iridescent, and structural pigment spots, which females actively evaluate during mate choice. Bright male ornamentation often enhances mating success but simultaneously increases visibility to predators, creating a quantifiable trade-off between natural and sexual selection [34]. This dynamic has established the guppy as a classic vertebrate model for investigating how competing selective forces maintain phenotypic diversity.

Recent research indicates that female choice is not a static trait but is socially modulated. Female preferences may shift based on male rarity (the "rare male effect"), social familiarity, prior mating history, and prevailing environmental conditions. Such findings have enriched guppy science beyond fundamental color preference, contributing significantly to modern theories of context-dependent sexual signaling [35, 36].

Furthermore, guppies provide critical insights into social behavior. As shoaling fish, they exhibit measurable patterns of group cohesion, emergent leadership, information transfer, and predator dilution. Experimental manipulations involving food distribution, social familiarity, and robotic fish models have demonstrated that guppy shoals reorganize rapidly in response to environmental stimuli, rendering them invaluable for studying collective decision-making [37].

Predator-prey interactions remain pivotal to the study of this species. Exposure to predator cues elicits tighter shoaling, increased vigilance, reduced open-water swimming, and alterations in burst-escape responses. Some of these effects are immediate plastic reactions, while others become stabilized across generations, allowing researchers to distinguish between individual learning and inherited adaptation [38].

Because females produce multiple broods annually and offspring mature rapidly, guppies permit the direct observation of life-history evolution under manipulated levels of nutrition, population density, predation cues, or mate competition. Few vertebrate systems allow for such near-real-time tracking of adaptive reproductive shifts [39].

In summary, the guppy remains one of the most productive vertebrate models for understanding the mechanisms by which ecological pressures shape behavior, reproduction, and evolutionary trajectories.

6. Guppies in Genetics, Physiology, and Biomedical Investigations

Over the past decade, the utilization of *Poecilia reticulata* has extended significantly beyond the realm of ecology, permeating the fields of genetics, comparative physiology, and reproductive biomedical sciences. Advances in genomic sequencing have yielded enhanced transcriptomic resources, linkage maps, and a more profound understanding of the sex-linked inheritance patterns associated with male ornamentation and reproductive traits. These developments have established the guppy as a robust model for investigating genotype-phenotype interactions and the evolution of sex chromosomes [40].

Numerous conspicuous traits of the guppy—including somatic pigmentation, growth rates, fecundity, social reactivity, and the timing of maturation—exhibit high heritability while remaining ecologically plastic. This attribute renders the species exceptionally valuable for disentangling genetic architecture from developmental modulation. Recent investigations have demonstrated that both behavior and reproductive performance are modulated by complex interactions between genotype, the social environment, nutritional status, and contaminant exposure [41-43]

From a physiological standpoint, the guppy provides practical advantages for examining metabolic shifts, locomotor decline, and stress adaptation throughout the ontogenetic cycle. Their relatively compressed life cycle facilitates the observation of age-related senescence in locomotor activity, oxygen consumption, and reproductive vigor within manageable experimental timeframes, underscoring their utility in vertebrate gerontology [44].

Reproductive physiology represents another particularly prolific area of inquiry. As viviparous teleosts characterized by internal fertilization, guppies permit the investigation of sperm competition, long-term female sperm storage, the modulation of inter-brood intervals, and cryptic female choice. Factors such as male density, nutritional stress, endocrine disruptors, and thermal fluctuations have been shown to alter sperm motility, insemination success, and offspring viability [45].

Contemporary reproductive toxic physiology has employed the guppy to evaluate the effects of perfluoroalkyl substances, phthalates, and wastewater effluents, revealing significant alterations in testicular transcriptomes, oxidative stress pathways, and fertility endpoints. Such studies indicate that the guppy can serve as a mechanistically informative model for environmentally induced reproductive dysfunction in vertebrates [46, 47].

Furthermore, their cortisol-mediated hypothalamic-pituitary-interrenal axis renders them highly suitable for stress biology research, while their conspicuous pigmentation facilitates the study of chromatophore regulation and carotenoid metabolism. Although the species does not yet possess the extensive transgenic toolkit available for zebrafish (*Danio rerio*), the guppy occupies a unique middle ground between ecological authenticity and molecular accessibility [48].

To the characteristics of guppies in comparison with zebrafish and Japanese medaka, Table 2 presents the most salient biological and methodological attributes of these species.

7. Scientific Trends, Limitations, and Future Perspectives

The scientific trajectory of *Poecilia reticulata* reveals a model organism undergoing significant methodological expansion. A primary trend is the convergence of classical ecology with molecular biology. Researchers are increasingly integrating predator simulations, social manipulation, and pollutant exposure with transcriptomic profiling, endocrine biomarkers, and oxidative stress measurements. This systems-level approach facilitates not only the description of phenotypic responses in guppies but also the rigorous investigation of their underlying biological mechanisms [49].

Table 2. Comparative Characteristics of Guppy, Zebrafish and Japanese Medaka as Laboratory Fish Models

Characteristic	Guppy (*P. reticulata*)	Zebrafish (*Danio rerio*)	Medaka (*Oryzias latipes*)
Reproduction	Live-bearing	Egg-laying	Egg-laying
Fertilization	Internal	External	External
Main strengths	Behavioural ecology, ecotoxicology, reproductive biology	Developmental genetics, transgenics	Developmental toxixology, carcinogenesis
Sexual dimorphism	Very pronounced	Moderate	Moderate
Molecular toolkit	Moderate	Extensive	Extensive
Social behavior complexity	Very high	High	Moderate
Embryo accessibility	Limited	Excellent	Excellent
Ecological realism	Excellent	Moderate	Moderate
Maintenance cost	Low	Low	Low

A second prominent trend is the increased utilization of guppies in the analysis of sub lethal contaminants. Modern toxicology has shifted its focus away from acute mortality, prioritizing instead:
* Reductions in fecundity and reproductive output.
* Endocrine interference and hormonal disruption.
* Immunological compromise.
* Chronic stress indicators.

Because guppies manifest these physiological and behavioral changes both conspicuously and rapidly, they are particularly advantageous for developing ecologically realistic exposure models [50].
Furthermore, there is an increasing recognition of the guppy's potential in comparative gerontology and stress physiology. Their abbreviated lifespan and the measurable, age-related decline in locomotor and reproductive parameters offer a unique window into vertebrate senescence. The implementation of automated behavioral tracking and high-throughput molecular analyses will likely further enhance the precision and reproducibility of future investigations [51].
Despite these advancements, several limitations persist:
* Standardization: Husbandry protocols remain less internationally standardized than those for established models like the zebrafish (*Danio rerio*).
*Heterogeneity: Research often exhibits significant variance regarding age cohorts, sex composition, nutritional regimes, and social density, which diminishes the comparability of data across different laboratories.
* Molecular Infrastructure: While improving, the molecular toolkit for guppies still lacks the depth and versatility of established transgenic fish models.

A persistent misconception in the scientific community is the characterization of guppies as merely "hardy" aquarium fish necessitating minimal welfare management. In reality, their behavioral and reproductive parameters are exquisitely sensitive to environmental perturbations. Consequently, future progress in this field depends not only on the adoption of emerging technologies but also on a more rigorous harmonization of reporting standards, aquatic welfare monitoring, and transparency in husbandry practices [52].

8. Conclusions

The guppy (*Poecilia reticulata*) has transitioned from a primarily ornamental species into a versatile and increasingly prominent vertebrate laboratory model. Its diminutive body size, rapid maturation, high fecundity, pronounced sexual dimorphism, and robust environmental responsiveness render it exceptionally suited for a diverse array of scientific disciplines—notably behavioral ecology, ecotoxicology, reproductive physiology, and comparative genomics.

A primary strength of this species lies in its unique synthesis of ecological realism and laboratory tractability. Guppies enable researchers not only to document mechanistic biological responses but also to interpret these findings within ecologically and adaptively significant contexts. Concurrently, their successful scientific utilization necessitates meticulous husbandry, welfare-oriented management, and strict adherence to contemporary ethical principles governing vertebrate experimentation.

While it is improbable that the guppy will supersede established models such as the zebrafish or medaka in highly specialized molecular developmental studies, it offers a strategic, complementary model wherein reproductive sensitivity, social complexity, and environmental responsiveness coexist within a cost-effective laboratory framework. As the biological sciences increasingly pursue integrative models that bridge welfare-conscious experimentation with translational ecological perspectives, *Poecilia reticulata* is poised to maintain and further consolidate its scientific relevance.

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