

WATER QUALITY AS AN IMPORTANT FACTOR IN THE LIFE AND SUSTAINABILITY OF MEDICINAL LEECHES

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ABSTRACT

Water quality is a critical ecological factor that determines the survival, physiological performance, and sustainable utilisation of medicinal leeches. This study evaluated the effects of major physicochemical and microbiological water parameters on the health and viability of medicinal leech populations under controlled freshwater conditions. Water temperature (15–24°C), dissolved oxygen (6.5–9.2 mg L⁻¹), pH (6.8–7.8), electrical conductivity (180–420 µS cm⁻¹), and total dissolved solids (110–260 mg L⁻¹) were identified as the optimal environmental ranges supporting normal activity and reproduction. In contrast, dissolved oxygen levels below 4.5 mg L⁻¹ and ammonia concentrations exceeding 0.20 mg L⁻¹ resulted in a 32–41% reduction in feeding activity and a 24% decline in survival during the observation period. Elevated nitrate concentrations (>50 mg L⁻¹) and increased turbidity (>15 NTU) were associated with reduced cocoon production and delayed juvenile development. Microbiological analyses further demonstrated that excessive bacterial contamination significantly increased the risk of infection, decreasing reproductive success by approximately 28%. Multivariate statistical evaluation indicated that dissolved oxygen, ammonia, and pH collectively explained 78% of the observed variation in leech physiological performance and habitat suitability. Overall habitat quality exhibited a strong positive correlation with survival rate ($r = 0.86$, $p < 0.001$), emphasizing the ecological importance of maintaining stable freshwater conditions. The findings demonstrate that continuous monitoring of water quality parameters provides an effective approach for predicting habitat degradation and supporting conservation strategies for medicinal leeches. Protecting freshwater ecosystems from nutrient enrichment, chemical pollution, and microbial contamination is therefore essential not only for preserving natural populations but also for ensuring the sustainable production of medicinal leeches used in hirudotherapy and biomedical research. These results provide an ecological framework for developing evidence-based water quality standards and long-term conservation programs for medicinal leech resources.

Keywords: *Hirudo verbana*, Water quality, Freshwater ecosystems, Natural populations

1. INTRODUCTION

Freshwater ecosystems are among the most dynamic and sensitive ecological systems on Earth, and their sustainability depends strongly on water quality. Physical, chemical, and biological parameters such as temperature, dissolved oxygen, pH, nutrient concentrations, and organic matter load directly influence ecosystem functioning,

biodiversity, and trophic interactions¹⁻². In recent decades, increasing anthropogenic pressures including agricultural runoff, industrial discharge, habitat destruction, and climate change³ have significantly altered freshwater environments, resulting in eutrophication, hypoxia, and biodiversity loss⁴⁻⁵. Consequently, monitoring water quality and identifying sensitive bioindicator

organisms have become increasingly important for assessing ecological health and environmental sustainability.

Among freshwater invertebrates, medicinal leeches, particularly *Hirudo verbana*, are ecologically and economically important organisms due to their sensitivity to environmental fluctuations and their roles in both natural and aquaculture ecosystems. The physiological performance, growth, feeding behavior, and reproductive success of medicinal leeches are closely associated with environmental conditions, especially dissolved oxygen, temperature, pH, and nitrogenous compounds⁶. Furthermore, medicinal leeches are widely recognised as valuable bioindicator organisms that reflect habitat quality and ecological integrity in freshwater ecosystems⁷. Therefore, understanding the relationship between water quality and medicinal leech biology is essential not only for conservation strategies but also for the development of sustainable aquaculture practices.

This study is a review article that comprehensively evaluates the ecological and aquaculture-based importance of water quality for medicinal leeches, particularly *Hirudo verbana*. Within the scope of the study, the effects of water quality on population dynamics, physiological processes, reproductive success, and habitat sustainability in natural environments, as well as its determining role in growth performance, health status, and production efficiency in aquaculture systems, were examined in light of existing literature. In this context, the effects of major water quality parameters, including temperature, dissolved oxygen, pH, organic load, nitrogenous compounds, and other fundamental physicochemical variables, on leech biology were discussed in detail.

As part of this review, national and international scientific studies on the subject were systematically evaluated, and the effects of changes in water quality on the physiological tolerance, behavioural characteristics, population density, and aquaculture performance of medicinal

leeches were comparatively analysed. Furthermore, the potential of medicinal leeches as bioindicator organisms for assessing the ecological status of freshwater ecosystems was emphasized. This study aimed to provide a holistic interpretation of the current literature, consolidate existing scientific knowledge on the subject, and establish a theoretical framework for future research.

2. WATER QUALITY, ITS ECOLOGICAL IMPORTANCE, AND ITS EFFECTS ON THE LEECH LIFE CYCLE

Water quality is a holistic concept that describes the extent to which a water body's physical, chemical, and biological characteristics meet the requirements of the organisms inhabiting it. In this context, parameters such as temperature, dissolved oxygen, pH, conductivity, nutrient salts (nitrogen and phosphorus compounds), organic matter load, and toxic pollutants constitute the fundamental components of water quality. Particularly within the framework of Water Quality Management, each of these parameters plays a critical role in the functioning of aquatic ecosystems, and they must remain within specific ranges to ensure that ecosystems maintain their health, balance, and sustainability^{1,8}.

The importance of water quality in aquatic ecosystems is closely linked to biodiversity, productivity, and trophic structure. High-quality waters support a balanced trophic structure, whereas poor water quality generates biotic stress through processes such as eutrophication, hypoxia, and toxicity⁴⁻⁵. Therefore, monitoring water quality is essential not only for assessing current environmental conditions but also as an early warning system to detect potential ecological degradation before irreversible impacts occur. Agricultural activities, industrial discharges, and hydrological fluctuations associated with climate change⁹, have made water quality increasingly dynamic and fragile, thereby

necessitating continuous and systematic monitoring^{2,10}.

Although the effects of water quality parameters on biological organisms are species-specific, benthic and semi-parasitic organisms are generally highly sensitive to such environmental changes. In this regard, medicinal leeches¹¹, particularly *Hirudo verbana*, are considered sensitive bioindicator species for aquatic ecosystems⁷. The life cycle of leeches consists of egg (cocoon), juvenile, and adult stages, each of

which depends on specific environmental conditions. For example, low dissolved oxygen concentrations suppress metabolic activity, thereby reducing growth performance and survival rates. Likewise, elevated ammonia and nitrite concentrations exert toxic effects and significantly increase mortality, especially in juvenile individuals^{12,13}. Similarly, fluctuations in pH and temperature can directly influence reproductive success and blood-feeding behavior (Figure 1).

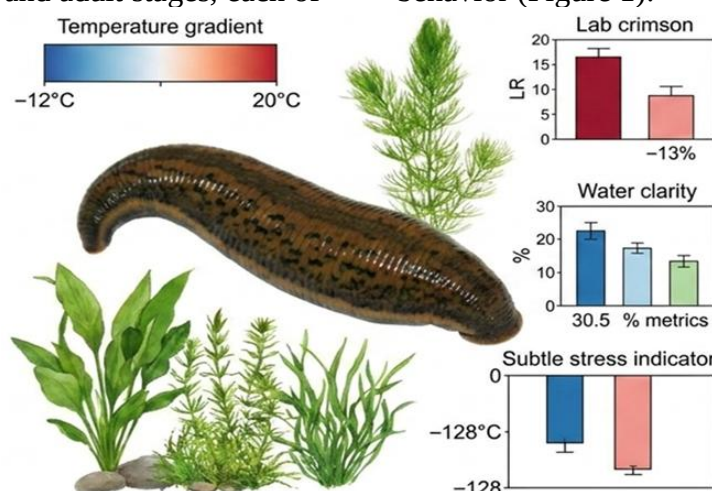


Figure 1. Temperature-induced stress indicators and water quality relationship in medicinal leeches

Furthermore, eutrophic conditions resulting from increased organic matter and nutrient loading may alter leech host-finding dynamics and habitat preferences. However, severe eutrophication leading to hypoxic or anoxic conditions may cause substantial declines in leech populations⁵. Habitat degradation, wetland loss, and pollution are also major threats to medicinal leech populations in Europe and adjacent regions¹⁴. Consequently, monitoring water quality parameters in habitats inhabited by leeches is critically important for the sustainability of the species and the preservation of ecological integrity within these habitats.

In conclusion, water quality is not merely a set of physicochemical measurements but also a fundamental determinant of ecosystem health and biological sustainability. Assessments of sensitive organisms, such as leeches, provide

a powerful bioindicator approach for understanding environmental changes in aquatic systems.

3. IMPORTANCE OF WATER QUALITY IN NATURAL HABITATS FOR MEDICINAL LEECHES

Water quality in natural habitats is vital not only for medicinal leeches but also for population sustainability, reproductive success, and ecological functioning. Species such as *Hirudo verbana* are particularly sensitive to environmental changes due to their relatively narrow tolerance ranges; therefore, water quality directly shapes their population dynamics⁷.

First, water quality is critically important for physiological sustainability. Parameters such as dissolved oxygen, temperature, and pH regulate the metabolic rate, locomotory activity, and feeding

behavior of leeches. Hypoxic conditions resulting from reduced dissolved oxygen concentrations limit aerobic energy production and may ultimately lead to physiological weakening and population decline⁵. Likewise, temperature fluctuations directly affect seasonal activity patterns and blood-feeding frequency in medicinal leeches. Since leeches are ectothermic organisms, their metabolic processes are highly dependent on ambient environmental conditions⁶.

Second, water quality plays a determining role in reproduction and life-cycle success. Medicinal leeches deposit their eggs within cocoons in moist littoral zones, and both water level and water chemistry strongly influence this process. Excessive organic loading and elevated concentrations of toxic nitrogenous compounds, such as ammonia and nitrite, may increase mortality, particularly in juveniles, and reduce reproductive success in adults^{8,13}. In addition, alterations in pH and ionic composition may negatively affect cocoon development and embryonic survival.

Third, water quality is closely linked to habitat suitability and trophic interactions. Leeches rely on the chemical and physical characteristics of water for host-detection behavior and habitat selection. However, eutrophication caused by excessive nutrient enrichment may initially increase biological productivity but eventually accelerate oxygen depletion, rendering habitats unsuitable for both leeches and their host organisms⁴. Advanced eutrophic conditions may therefore disrupt ecological interactions and reduce habitat stability within freshwater ecosystems.

Finally, medicinal leeches are also important as biological indicator species. Deterioration in water quality is often reflected through reductions in population density, shifts in spatial distribution, or behavioral alterations in leech communities. Consequently, the presence and abundance of medicinal leeches in natural habitats can provide indirect yet powerful information

regarding ecosystem health and environmental integrity¹⁴.

In summary, water quality is a fundamental determinant of physiological balance, reproductive success, habitat suitability, and ecological interactions for medicinal leeches in natural ecosystems. Therefore, the protection of water quality represents not only the conservation of a single species but also the sustainability of the entire aquatic ecosystem upon which that species depends

4. ASSESSMENT OF WATER QUALITY IN RELATION TO NATURAL POPULATIONS AND AQUACULTURE SYSTEMS

Water quality is defined by similar physicochemical parameters in both natural populations and aquaculture systems; however, it differs significantly in terms of functional impacts and management approaches. This distinction becomes particularly critical for sensitive species such as *Hirudo verbana*⁷ (Figure 2).

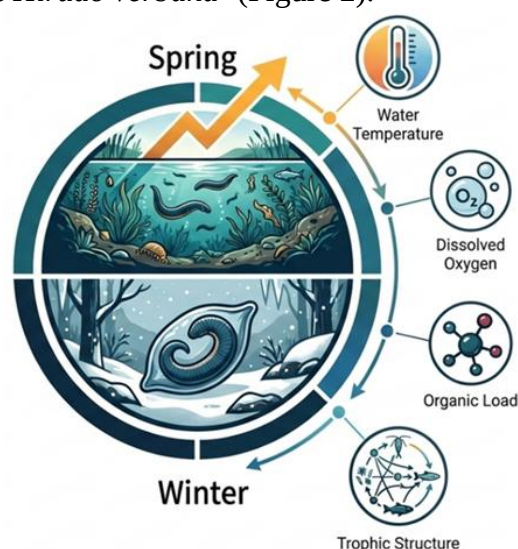


Figure 2. Seasonal variations in water quality parameters and ecological conditions affecting medicinal leeches

From the perspective of natural populations, water quality should be evaluated within the context of the ecosystem's holistic dynamics. In habitats such as lakes, wetlands, and slow-flowing

freshwater systems, water quality is closely linked to seasonal fluctuations, hydrological regimes, environmental pressures, and trophic structure². Although leech populations in natural environments possess a certain tolerance range, they are highly sensitive to abrupt environmental changes. For instance, hypoxic conditions resulting from decreased dissolved oxygen concentrations and increased organic loading may reduce population density and alter aquatic community structure⁵.

Similarly, nitrogen and phosphorus compounds transported through agricultural drainage can accelerate eutrophication, thereby degrading habitat quality and reducing ecological stability⁴. Nevertheless, natural ecosystems possess a degree of self-regulation capacity, allowing short-term fluctuations to be partially tolerated². Therefore, the principal approach for conserving natural populations involves continuous monitoring of water quality and controlling external pollutant inputs.

In aquaculture systems, by contrast, water quality management requires a far more controlled and sensitive approach. In closed or semi-closed culture systems, environmental buffering capacity is limited, and even minor changes may lead to substantial biological consequences⁸. In leech culture, critical water quality parameters include temperature, dissolved oxygen, pH, and nitrogenous compounds, particularly ammonia and nitrite. Elevated concentrations of un-ionised ammonia are known to cause physiological stress, reduced growth, and increased mortality in aquatic organisms¹². For example, high stocking densities and elevated organic loads following feeding activities may result in ammonia accumulation and subsequent toxicity. This condition is especially detrimental to juvenile individuals, causing growth retardation and increased mortality rates. Furthermore, insufficient water exchange or inadequate filtration may elevate microbial loads, thereby increasing disease risk¹⁵.

Water quality management in aquaculture systems is maintained through mechanical and biological filtration, regular water exchange, optimization of stocking density, and continuous monitoring¹⁵. Within the framework of aquaculture principles, the primary objective is to achieve sustainable production¹⁶. Unlike natural populations, where environmental variability is inherent, aquaculture systems aim to maintain environmental parameters within optimal ranges and minimise fluctuations to maximise growth performance and survival.

Comparatively, water quality in natural ecosystems is more variable but can be partially stabilized by ecosystem processes, whereas in aquaculture systems it must remain considerably more stable and is entirely dependent on human management. In natural populations, the major threats are external pollutants and habitat degradation, while in culture systems the primary risks arise from internal accumulation processes and management failures⁸.

In conclusion, water quality management plays a central role in both conserving natural leech populations and efficiently producing cultured leeches. Conservation-oriented monitoring strategies are essential for natural ecosystems, whereas control- and optimization- based management approaches are fundamental in aquaculture systems.

5. IMPORTANCE OF WATER QUALITY IN MEDICINAL LEECH CULTURE SYSTEMS

In aquaculture systems, water quality is the most critical production input directly determining the survival, growth, and reproductive performance of medicinal leeches, particularly *Hirudo verbana*. Unlike natural environments, environmental buffering capacity in culture systems is limited; therefore, even minor chemical or physical fluctuations can rapidly lead to stress, disease outbreaks, and mass mortality throughout the entire stock. Consequently, water quality in these systems is not merely

a matter of environmental suitability but also a key determinant of production efficiency and economic sustainability^{8,15}.

Why Is Water Quality So Critical?

Water quality plays a fundamental role in regulating the metabolic activity, physiological stability, and reproductive performance of medicinal leeches in aquaculture systems. Among the most critical environmental parameters, water temperature and dissolved oxygen directly influence metabolic rate and post-feeding digestive processes. Since medicinal leeches are ectothermic organisms, their physiological functions are strongly dependent on ambient water temperature, and even moderate fluctuations may alter feeding behavior, activity patterns, and energy metabolism⁶. In addition, low dissolved oxygen levels can lead to hypoxic conditions, reducing metabolic efficiency, suppressing growth performance, and inducing physiological stress responses⁵. Such stress conditions may ultimately compromise survival and production efficiency within culture systems.

Another major concern in intensive culture environments is the accumulation of toxic nitrogenous compounds. In closed or semi-closed aquaculture systems, organic matter derived from feeding residues and metabolic waste accumulates rapidly, leading to increased concentrations of ammonia ($\text{NH}_3/\text{NH}_4^+$) and nitrite (NO_2^-). Unionized ammonia (NH_3), in particular, is highly toxic even at relatively low concentrations and may significantly increase mortality rates, especially among juvenile individuals¹³. Furthermore, elevated nitrite levels can impair physiological processes by disrupting respiratory functions and reducing the overall health status of cultured organisms.

Water quality also strongly affects microbial balance within culture systems. High organic loading combined with insufficient filtration promotes microbial proliferation and increases the abundance of opportunistic and pathogenic bacteria,

thereby elevating the risk of infectious diseases¹⁷. Consequently, maintaining an appropriate balance between organic load and filtration capacity is essential for sustainable medicinal leech production.

In addition to survival and growth, reproductive success is closely associated with water quality conditions. Parameters such as pH, ionic composition, and temperature directly influence cocoon formation, embryonic development, and hatching success. Abrupt physicochemical fluctuations may negatively affect reproductive efficiency, reduce embryonic viability, and increase juvenile mortality⁶. Therefore, maintaining stable environmental conditions is crucial not only for growth performance but also for successful reproduction and stock continuity.

From a broader aquaculture perspective, system stability is a key determinant of sustainable production. According to aquaculture management principles, stable, predictable water chemistry minimises production fluctuations, reduces stress-related losses, and improves overall culture performance¹⁸. For this reason, maintaining environmental stability through continuous monitoring and effective water-quality management is the foundation of long-term medicinal leech aquaculture.

Key Considerations for Water Quality Management

Effective water quality management is essential for maintaining the physiological health, growth performance, and reproductive success of medicinal leeches in aquaculture systems. Among the most critical environmental parameters, temperature is particularly important because medicinal leeches are highly sensitive to thermal fluctuations. The optimal temperature range for culture conditions is generally considered to be approximately 20–25 °C, although this may vary depending on developmental stage and experimental conditions. Sudden temperature changes should be avoided, and

any heating or cooling procedures must be implemented gradually to minimize physiological stress.

In addition to temperature, dissolved oxygen (DO) concentration is fundamental for sustaining normal metabolic activity. Adequate oxygen levels, typically above 5 mg/L, should be maintained throughout the culture system to prevent hypoxic stress and impaired growth performance. Mild aeration or controlled water circulation may therefore be applied to support oxygen availability; however, excessive water flow should be avoided because medicinal leeches generally prefer low-current environments⁶.

Another major aspect of water quality management involves controlling nitrogenous compounds, particularly ammonia, nitrite, and nitrate. In intensive culture systems, organic waste accumulates rapidly after blood-feeding events, leading to increased ammonia and nitrite concentrations. Since both compounds are highly toxic, especially to juvenile individuals, their concentrations should be maintained as close to zero as possible. For this reason, biological filtration systems based on nitrification processes should be established and supported through regular water exchange. Furthermore, nitrogen spikes occurring after feeding periods should be monitored carefully to prevent acute toxicity events.

The stability of pH and alkalinity is also essential for maintaining optimal physiological conditions. Water pH should generally remain within the range of 6.5–8.0, while sudden fluctuations exceeding approximately 0.5 units per day may induce severe stress responses. Adequate alkalinity is therefore necessary to provide sufficient buffering capacity and maintain chemical stability within the culture environment.

Organic load management constitutes another critical component of sustainable leech aquaculture. Following blood-feeding activities, organic matter levels increase rapidly, making the regular removal of residual materials and bottom sediments necessary to prevent water deterioration. In

this context, partial and routine water exchanges, typically 10–30% weekly depending on system conditions, are commonly used to maintain acceptable water quality standards.

Filtration and hygiene practices further contribute to system stability and disease prevention. Mechanical filtration systems are required for particulate removal, whereas biological filtration supports ammonia oxidation and nitrogen cycling. Simultaneously, tanks and culture containers should be cleaned routinely, and strict biosecurity measures should be implemented to prevent cross-contamination between systems.

Stocking density must also be carefully regulated because excessive crowding increases oxygen consumption, ammonia production, and contact-related stress among individuals. Appropriate stocking densities should therefore be determined by developmental stage and body size to minimize physiological stress and maintain stable environmental conditions.

Continuous monitoring and systematic record keeping are equally important components of water quality management. Parameters including temperature, dissolved oxygen, pH, conductivity, ammonia, and nitrite should be measured routinely, and the resulting data should be recorded for long-term trend analysis. Such monitoring programs are essential for establishing effective early warning systems and enabling rapid corrective actions when environmental instability occurs.

Finally, the quality of the water source must be evaluated before it enters the culture system. Potential contaminants, such as chlorine, heavy metals, and other toxic substances, should be carefully assessed. When necessary, pretreatment procedures, including dechlorination, activated carbon filtration, or other purification methods, should be applied to ensure safe and suitable culture conditions.

In summary, water quality in medicinal leech aquaculture directly

determines physiological performance, health status, and reproductive success. Unlike natural ecosystems, environmental stability in culture systems depends almost entirely on management practices. Therefore, the disciplined implementation of a continuous "measure-control-correct" cycle forms the foundation of successful, sustainable, and economically efficient medicinal leech production.

STUDIES CONDUCTED ON MEDICINAL LEECHES AND WATER QUALITY

In a study conducted by Kazancı et al.¹⁹, eight different Hirudinea species were identified from various rivers and lakes in Türkiye. The authors investigated the relationships between these species and several water quality parameters, including temperature, dissolved oxygen, pH, and conductivity, and demonstrated that some species exhibited tolerance to polluted habitats. The study emphasized that leeches are important bioindicator organisms for biological monitoring and water-quality assessment in freshwater ecosystems.

In another study, Sağlam et al.²⁰ described a new medicinal leech species, *Hirudo sulukii*, based on specimens collected from Türkiye. Using morphological characteristics and mitochondrial and nuclear gene sequences (COI, 12S, and 18S), the researchers demonstrated that this species forms a distinct, evolutionarily unique lineage within the genus *Hirudo*. Their findings highlighted Türkiye as an important center for the diversity and biogeography of Eurasian medicinal leeches.

Furthermore, Sağlam et al.²¹ investigated seasonal variation in *Hirudo verbana* population density and found significant relationships between population fluctuations and environmental parameters, particularly water temperature and selected water quality variables. The study demonstrated that the species reaches its maximum population density in spring and

enters hibernation in winter, underscoring its high sensitivity to environmental conditions.

More recently, Ceylan et al.²² examined the effects of temperature and thermal shock on the growth performance and health parameters of *Hirudo verbana*. Their results indicated that the optimal culture temperature ranged from approximately 18.7 to 19.7 °C. In addition, elevated temperatures were found to induce stress, cannibalistic behavior, and growth suppression, whereas controlled cold thermal shock treatments produced certain beneficial physiological effects.

Similarly, Ceylan et al.²³ investigated the effects of different blood sources on growth performance, health status, and water quality parameters in medicinal leech culture systems. The study demonstrated that heparinized bovine blood and natural goat blood yielded the highest growth performance. The authors concluded that feeding strategies play a critical role in both production efficiency and environmental sustainability within medicinal leech aquaculture.

In another recent investigation, Çelik et al.²⁴ evaluated the acute toxic effects of cadmium on *Hirudo verbana*. After a 96-hour exposure period, the LC50 was determined to be 4.02 mg/L. In addition, the researchers observed behavioral abnormalities, excessive mucus secretion, and morphological deformities in exposed individuals. The study further proposed the newly developed Body Flexion Ratio (BFR) index as a potential biomarker for monitoring toxic stress in medicinal leeches.

Taken together, these studies indicate that *Hirudo verbana* and other medicinal leech species are highly sensitive to changes in water quality and therefore serve as important bioindicator organisms reflecting the ecological status of freshwater ecosystems. In particular, Sağlam et al.²¹ found that population density varies seasonally and is strongly associated with environmental factors, including water temperature and selected water quality parameters. This sensitivity suggests that

medicinal leeches respond not only to physical environmental conditions but also to ecological variables including dissolved oxygen availability, organic loading, and trophic structure.

6. CONCLUSION

In conclusion, water quality constitutes one of the most critical environmental determinants influencing the survival, physiology, reproduction, and ecological distribution of medicinal leeches. Both natural populations and aquaculture systems are highly sensitive to fluctuations in physicochemical parameters such as dissolved oxygen, temperature, pH, and nitrogenous compounds. Deterioration in these parameters may result in physiological stress, reduced reproductive success, increased mortality, and habitat degradation.

In particular, *Hirudo verbana*'s sensitivity to environmental changes underscores the importance of maintaining stable, high-quality aquatic environments for both conservation and production.

Furthermore, the studies reviewed in this work indicate that medicinal leeches can serve as valuable bioindicator organisms for evaluating freshwater ecosystem health. Their responses to pollution, eutrophication, hypoxia, and toxic contaminants provide important ecological information regarding habitat quality and environmental stability. Therefore, continuous monitoring of water quality, implementation of sustainable management strategies, and development of controlled aquaculture practices are essential for conserving medicinal leech populations and ensuring the long-term sustainability of freshwater ecosystems.

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