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Study uses passive acoustic monitoring to quantify effects of temperature, ammonia and nitrite nitrogen on Pacific white shrimp feeding

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Results demonstrated a significant correlation between the number of clicks and feed consumption in shrimp across different environmental treatments

Study uses passive acoustic monitoring to quantify effects of temperature, and ammonia and nitrite nitrogen concentration on Pacific white shrimp feeding. Results demonstrated a significant correlation between the number of clicks and feed consumption in shrimp across different environmental treatments. This study is the first to quantify specific effects of common environmental factors on the acoustic feeding signals and feeding behavior of P. vannamei using PAM technology. Photo of auto-feeders in a commercial shrimp pond by Fernando Huerta.

In the complex environment of pond aquaculture, passive acoustic monitoring (PAM) technology has demonstrated considerable potential in **intelligent feeding systems** (https://doi.org/10.1111/raq.12978)for shrimp pond farming due to its independence from visual limitations. Previous studies have shown that the continuous "click" acoustic signals emitted by *P. vannamei* during feeding are closely related to feed consumption. Quantifying and analyzing the characteristic parameters of these acoustic signals can assess shrimp feeding behavior and serve as **pivotal data support** (https://doi.org/10.1111/raq.12546) for real-time monitoring of shrimp feeding status.

Fluctuations in environmental factors in pond aquaculture significantly **affect the feeding behavior of shrimp** (https://www.cabidigitallibrary.org/doi/abs/10.1079/9781800629363.0012). For instance, ammonia nitrogen concentrations above 4 mg/L can lead to the enrichment of intestinal pathogens in shrimp, suppressing their appetite and reducing feeding behavior; and exposure to a concentration of 20 mg/L nitrite nitrogen disrupts the intestinal mucosal structure of shrimp, further inhibiting their feeding. Additionally, shrimp feed intake decreases with decreasing temperature within a specific range, and temperatures below 20 degrees-C impair their immune defense. Currently, automatic water quality monitoring systems can obtain **real-time environmental parameters** (https://doi.org/10.3390/s22062088) and have been preliminarily applied in pond aquaculture management.

However, most existing PAM-based intelligent feeding systems operate independently from water quality monitoring systems, resulting in a lack of information exchange between them. This design limitation, which excludes environmental factors, **monitoring accuracy and feeding precision** (https://doi.org/10.1111/raq.12282) of feeding systems in the complex environment of pond aquaculture. Therefore, there is a need to establish a direct pathway from environmental data to behavioral and passive acoustic data, efficiently integrating multi-source information to enhance the response rate of feeding systems and improve the timeliness and scientific basis of feeding decisions.

This article – **summarized** (https://creativecommons.org/licenses/by/4.0/)from the **original publication** (https://doi.org/10.3390/ani15142113) (Zhang, H. et al. 2025. Environmental Factors Modulate Feeding Behavior of *Penaeus vannamei*: Insights from Passive Acoustic Monitoring. *Animals* 2025, 15(14), 2113) – reports on a study that used temperature, ammonia nitrogen concentration, and nitrite nitrogen concentration as key environmental variables to analyze the correlation between feed consumption and feeding acoustic characteristics and quantified the effects of these environmental factors on the feeding behavior and acoustic characteristics of *P. vannamei*.

Study setup

The study was conducted at the Key Laboratory of Mariculture, Ministry of Education, Ocean University of China. The *P. vannamei* (average weight 8 ± 0.32 grams) used in the experiment were sourced from Yellow River Delta Marine Technology Co., Ltd., Dongying City, Shandong Province, China. Throughout the experiment, consistent natural seawater conditions were maintained. To establish a connection between environmental factors and the feeding acoustics of *P. vannamei,* this study utilized PAM technology combined with video analysis to evaluate the effects of three key environmental factors – temperature, ammonia nitrogen, and nitrite nitrogen – on the feeding behavioral characteristics of shrimp, with a specific focus on acoustic signals “clicks.”

Following acclimation, 660 *P. vannamei* in the intermolt period with intact appendages and normal activity were randomly selected and transferred to 11, 216-L experimental tanks, with 60 shrimp per tank. The experimental design included three independent sets conducted simultaneously, with gradients sets for temperature, ammonia nitrogen and nitrite nitrogen. Acoustic feeding signals from shrimp under different environmental conditions were collected using an audio acquisition system equipped with a commercial hydrophone (Soundtrap 300 STD, Ocean Instruments, New Zealand) (Figure 1A).

For detailed information on the experimental design and equipment, animal husbandry, and data acquisition and analysis, refer to the original publication.

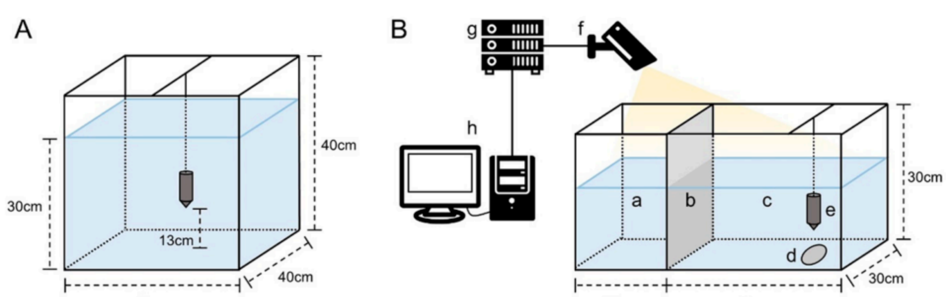

Fig. 1: Audio acquisition system (A) and feeding behavior observation system (B). Note: isolation zone (a), partition (b), observation zone (c), feeding tray (d), hydrophone (e), infrared camera (f), switch (g), monitor and storage device (h).

Results and discussion

This study analyzed feed consumption, acoustic feeding signals, and feeding behavior in *P. vannamei* under varying conditions of temperature, ammonia nitrogen, and nitrite nitrogen. Within the range of variation of the environmental factors tested, a rise in temperature is associated with an increase in feed consumption, the number of clicks, and sound pressure level (SPL).

Conversely, elevated concentrations of ammonia nitrogen and nitrite nitrogen led to a decrease in feed consumption and the number of clicks, while exerting minimal influence on SPL. Notably, a stable correlation was observed between feed consumption and the number of clicks across different environments. Additionally, these environmental factors significantly influenced a variety of feeding-related behaviors in *P. vannamei*.

The characteristic parameters of the "click" acoustic signals emitted by shrimp during feeding, including the timing, the number of pulses, and SPL, possess considerable significance in the monitoring of feeding behavior and aquaculture management. Our study revealed a notable correlation between feed consumption and the number of clicks in *P. vannamei* across different environments (Fig. 2). Compared to SPL, the number of clicks emerged as a more reliable parameter for monitoring the feeding status of shrimp.

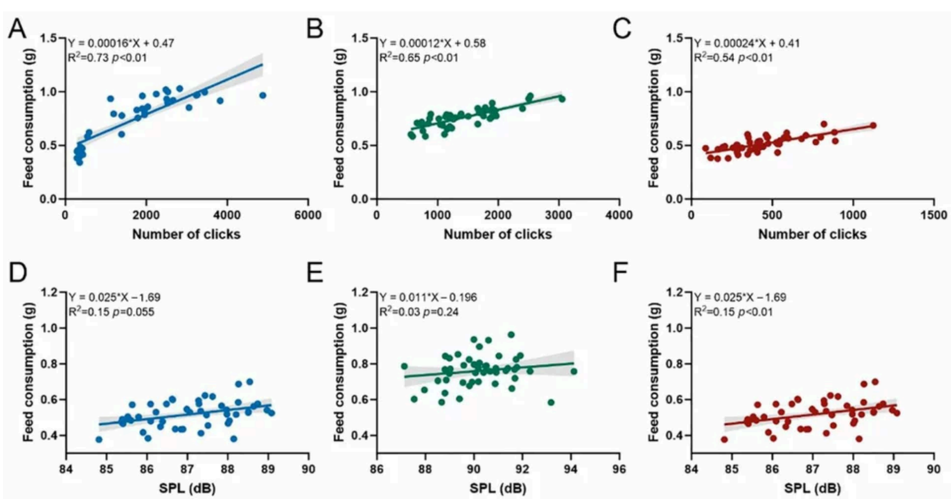

Fig. 2: Relationships between feed consumption and both the number of clicks (A–C) and sound pressure level (SPL, in dB) (D–F) within 30 min after pellet feeding, under different temperatures, ammonia nitrogen concentrations, and nitrite nitrogen concentrations.

Additionally, we found that in various environments, both the number of clicks and SPL decreased as feeding duration progressed, with the highest click count proportion and peak SPL occurring within the initial 10 min. This observation suggests that shrimp exhibit the highest feeding frequency and intensity during this period, aligning with the findings reported by other researchers. Based on our results, future research should prioritize the number of clicks generated during the initial feeding phase of shrimp and integrate acoustic signal characteristics under complex environmental conditions to enhance the precision of intelligent feeding systems.

In aquaculture ponds, an increase in temperature within the optimal range accelerates the metabolic rate of *P. vannamei*, enhances energy demand, and stimulates feeding activity. Consistent with previous studies, our research also found that as temperature rises, the feed consumption, the number of clicks, and the SPL of shrimp all exhibit an upward trend (Fig. 3A–C).

Fig. 3: Differences in feed consumption, number of clicks, and sound pressure level (SPL, in dB) of P. vannamei within 30 min after pellet feeding, under varying temperatures (A–C), ammonia nitrogen concentrations (D–F), and nitrite nitrogen concentrations (G–I). Different lowercase letters indicate significant differences between treatment groups ($p < 0.05$).

Furthermore, the proportion of feeding time increased, while foraging time significantly shortened (Fig. 4A,B), and the trajectories of shrimp concentrated around the feeding trays. Conversely, shrimp exhibited reduced swimming and feeding behavior at 20 degrees-C.

Fig. 4: Proportion of behavior time and the foraging time of P. vannamei under different temperatures (A,B), ammonia nitrogen concentrations (C,D), and nitrite nitrogen concentrations (E,F). Different uppercase letters indicate significant differences between behaviors within the same treatment, while different lowercase letters indicate significant differences in the same behavior across treatments.

The classical temperature–metabolism relationship is defined by the Q10 coefficient, typically following Q10 = 2.0. This study found Q10 values of 2.12 across the 26–32 degrees-C interval but 13.82 in the 20–26 degrees-C interval, representing a significant deviation from the typical value in the lower temperature. This discrepancy likely arises because 20 degrees-C falls outside the optimal metabolic range for shrimp and suppresses feeding activity. These findings align with behavioral observations showing that shrimp at 20 degrees-C failed to reach the feed tray, indicating that low temperatures impact feeding more profoundly than high temperatures within the tested gradient.

Therefore, close attention should be paid to water temperature fluctuations in pond culture of *P. vannamei*. By integrating temperature and PAM information, an intelligent feeding system that synergistically monitors both temperature and PAM can be devised to dynamically adjust feeding amount. Specifically, when water temperature rises, feeding amounts should be appropriately increased, and feeding strategies optimized based on real-time changes in the number of clicks to enhance feeding efficiency and growth rate of shrimp. On the contrary, when water temperature decreases, feeding amounts should be reduced to minimize feed waste and water pollution. However, temperature exhibits inhibitory effects on both feeding activity and growth performance in shrimp when exceeding optimal ranges.

In shrimp pond aquaculture systems, unlike dissolved oxygen and salinity, which are typically maintained within stable ranges, ammonia nitrogen and nitrite nitrogen dynamically accumulate as byproducts of feed metabolism. Their concentrations are notoriously difficult to regulate with real-time precision, a challenge that inherently decreases feeding efficiency in aquaculture animals. Our study also found that as ammonia nitrogen and nitrite nitrogen concentrations increased, the feed consumption of shrimp decreased (Fig. 3D,G) This was accompanied by an increase in foraging time and quiescent time, along with a reduction in feeding time (Figure 4C–F). Moreover, the number of clicks (Fig. 3E,F) and SPL (Fig. 3H,I) correspondingly decreased, indicating that the two nitrogen compounds inhibited the feeding of shrimp.

Behavioral trajectories showed that shrimp in water with high concentrations of these nitrogen compounds were more inclined to stay at their initial locations and less likely to reach the feeding trays. This may be due to nitrogen compounds damaging the gill tissue structure of shrimp, diminishing the oxygen-carrying capacity of hemocyanin. As a result, shrimp are compelled to adjust their behavioral adaptation strategies by reducing feed intake to conserve energy and enhance survival probability, which is consistent with the adaptation mechanisms of fish such as common carp.

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Based on our results, neglecting the impact of inorganic nitrogen on the feeding of shrimp may lead to delayed adjustment in feeding amounts, causing the accumulation of uneaten feed, elevated ammonia nitrogen and nitrite nitrogen concentrations, and ultimately resulting in a vicious cycle of water pollution and inhibited shrimp feeding. Therefore, in future assessments of feeding strategies, it is necessary to include ammonia nitrogen and nitrite nitrogen concentrations as key information in the decision-making process of PAM feeding systems. Specifically, the system should issue warnings when inorganic nitrogen concentrations rise and correspondingly reduce feed amounts to maintain the stability of the aquaculture environment and ensure the good growth of shrimp.

It is important to recognize that in actual aquaculture ponds, environmental factors such as temperature, ammonia nitrogen, and nitrite nitrogen do not exist in isolation. Instead, they interact in complex ways to produce combined effects on shrimp, amplifying stress effects and increasing the complexity and challenges of feeding management.

In summary, the number of clicks across various aquaculture environments consistently correlates with feed consumption, accurately reflecting the feeding status of shrimp. Compared to ammonia nitrogen and nitrite nitrogen, temperature variations exert a more pronounced impact on the feed consumption, acoustic characteristics, and behavior of *P. vannamei*, appearing as the most significant environmental factor influencing its feeding.

Perspectives

This study utilized PAM to investigate the effects of temperature, ammonia nitrogen, and nitrite nitrogen on the feeding behavior and acoustic signals of *P. vannamei*. Results reveal a significant positive correlation between the number of clicks and feed consumption, with temperature identified as the most influential environmental factor. Elevated temperatures stimulate feeding activity and acoustic signal intensity, whereas high concentrations of ammonia nitrogen and nitrite nitrogen suppress both parameters.

This research is the first to quantify environmental impacts on *P. vannamei* feeding acoustics, validating the feasibility of PAM for assessing feeding status across diverse conditions. The findings underscore the necessity of integrating environmental monitoring modules into intelligent feeding systems, providing a scientific foundation for the development of precision feeding technologies and the enhancement of aquaculture efficiency.

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