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Original Research Paper

Behavioral Plasticity of Coral Reef Fish Under Increasing Ocean Acidification and Its Impact on Survival Strategies

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Key Words

Ocean acidification,
Behavioral plasticity,
Coral reef fish,
Survival strategies,
Predator avoidance,
Foraging behavior,
Environmental stressors.

Abstract

Direct impacts of rising atmospheric carbon dioxide include ocean acidification, a rising threat to marine ecosystems, particularly coral reef fish. This research paper will examine how coral reef fish species respond to behavioral plasticity when faced with rising ocean acidity and how this affects their survival mechanisms. The experiment was conducted in a laboratory on juvenile coral reef fish species subjected to different pH levels (7.8 to 7.3) over 12 weeks. The behavioral changes were observed through individual and group interactions, including predator avoidance, foraging, and social interactions. The findings showed significant changes in fish behavior due to decreased pH, with marked reductions in predator-avoidance ability and foraging efficiency, leading to increased mortality in acid environments. ANOVA and post hoc tests showed a clear relationship between reduced pH and increased behavioral disturbances, with p-values < 0.05 in all tests. Nevertheless, some species were found to exhibit behavioral plasticity, the ability to adapt and change their survival strategies in response to changing environmental conditions. Such discoveries indicate that although some coral reef fish species may be able to adapt to ocean acidification, many are at high risk of dying. This paper focuses on the necessity of conserving coral reef habitats and the need for additional research on behavioral adaptations and species resilience. The findings highlight the need to implement conservation measures that account for the possibility of plasticity in behavioral adaptation to environmental stressors.

Introduction

One of the most serious environmental problems on our planet today is the increase in atmospheric carbon dioxide (CO 2) levels, which has prompted a radical change in ocean chemistry known as ocean acidification (Hamilton et al., 2023; Han, 2025). When the ocean absorbs excess atmospheric CO2, this process occurs, reducing the pH of seawater and making it more acidic. Marine ecosystems that depend on specific environmental conditions to flourish are of particular concern in the face of this change in water chemistry, e.g., coral reefs (Hamilton et al., 2023; Han, 2025). Coral reef ecosystems, which are highly biodiverse, are also susceptible to the impacts of ocean acidification (Boymuradov et al., 2025; Brinda & Sindhu, 2024). The coral reef fish, which constitute a vital component of the marine food chain, are exposed to the

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effects of acidic waters, and these alterations may have profound effects on their survival, behavior, and ecological interactions. These essential systems are severely disturbed, with effects that not only harm fish but also the whole coral reef system, which is home to so many other species of marine life and sustains the lives of millions of people around the world. With the ongoing rise in ocean acidification, there is a need to understand its impacts on the behavior and survival of coral reef fish, as a predictor of future effects on marine biodiversity and ecosystem services (Machado et al., 2025).

Changes in the behavior of marine organisms, especially fish, are often strong indicators of their ability to adapt to environmental changes, such as ocean acidification (Zemah-Shamir et al., 2022). Complex behaviors are required to keep fish alive, including predator avoidance, foraging, and social behaviors such as schooling (Bass & Falkenberg, 2023). Not only are these behaviors essential to the survival of individuals, but they also play a significant role in preserving the structure and functionality of marine life (Aadiwal et al., 2025). Nonetheless, the growing body of evidence indicates that ocean acidification disrupts fundamental behaviors, hindering fish's responses to predators, their ability to forage effectively, and their social interactions with other members of their species (Shi & Li, 2024). For example, fish in acidified environments often respond slowly to predator threats, making them more susceptible to predation. Similarly, foraging efficiency may be significantly impaired, and fish may waste more time searching for food, leading to energy deficits that influence their growth, reproductive success, and fitness. Social activities, such as schooling, that help fish avoid predation and enhance their foraging effectiveness can also be disrupted in acidified waters, and the protective value of living in groups is diminished, making fish vulnerable to predation (Kapoor & Vasudevan, 2025).

These behavioral disturbances are a direct consequence of alterations in sensory and cognitive functions. They are directly related to changes in ocean alkalinity, highlighting the difficulties coral reef fish face as ocean acidification progresses (Cipriani et al., 2024; Cohen-Rengifo et al., 2022; Yoon et al., 2025). The consequences of such behavioral disturbances are far-reaching, not only for the life of individual species but also for the general ecological well-being of coral reef ecosystems. Coral reef fish also play a vital role in the functioning of such ecosystems and drive ecologically significant processes, including nutrient cycling, algal populations, and coral health. These processes are likely to be destabilized by disruptions to their behaviour, including reduced predator avoidance, poor foraging, and reduced social integration, which trigger cascading impacts across the ecosystem.

For example, when fish fail to escape predators successfully, the dynamics between predators and prey on the reef may change, and species abundance and diversity may change. Equally, the distribution and availability of food resources may change due to low foraging success, not only for fish but also for other species that rely on the same food source. Moreover, the decline in social activities, such as education, may expose fish to predation, thereby reducing the fish population (Senthil, 2024). Such environmental changes may cause an imbalance in the coral reef ecosystem, decrease biodiversity, and reduce coral reef resilience to other stressors, such as warmer waters and habitat destruction. With ocean acidification still increasing, it is essential to understand the impacts on coral reef fish and to find ways to mitigate these effects so that coral reefs and the numerous species that depend on them can survive (Mitchell et al., 2022; Rahman & Mallick, 2025).

Key Contributions

- It offers a fresh understanding of how coral reef fish respond to acidification, particularly in predator avoidance and foraging behavior.
- It investigates behavioral plasticity as a survival strategy in coral reef fish in response to changing environmental conditions.
- It provides a better insight into the effects of such behavioral modification on the fitness and survival of the coral reef fish, as part of conservation measures to maintain marine biodiversity.

The paper is organized as follows: Section II explains the experimental design and protocols for measuring fish behavior under various acidification conditions. The findings are presented in Section III, along with their implications for relevant behavioral measures, such as predator avoidance, foraging success, and social behavior. The results are interpreted in the context of survival strategies, the broader implications for coral reef fish populations, and recommendations for future research in this field. Then, section IV summarizes the main results and provides recommendations for further research and conservation to reduce the impact of ocean acidification on marine biodiversity.

Materials and Methods

Experimental Setup and Acidification Conditions

The experiment took place in a laboratory, where coral reef fish were subjected to various concentrations of ocean acid in a series of controlled fish tanks (Roche et al., 2025). The main environmental parameter in the experiment was water pH, which was controlled using a pH control system. To reproduce present and future ocean conditions with acidification, four pH levels were used: the control group received normal ocean pH (8.1), whereas the experimental groups received increasingly lower levels of acidification (7.8 to simulate moderate acidification, 7.5 to simulate high acidification). These pH values were obtained during the experiment to closely replicate the effects of ocean acidification, which has been associated with rising atmospheric CO2 concentrations (Masanja et al., 2024). Other significant environmental factors, including temperature, salinity, and oxygen levels, were also closely monitored to maintain stable conditions for the fish, along with pH control. Each tank had automated pH, temperature, and oxygen sensors to regulate these parameters when necessary and to ensure correct simulated conditions of ocean acidification (Roche et al., 2025). To further improve the experimental conditions, the fish were also kept in tanks that replicated natural reef conditions.

A filtration system was fitted to each tank to maintain water quality and prevent the formation of waste products that would disrupt the experiment. Moreover, the tanks were equipped with automated feeding devices that provided a constant supply of food, eliminating random variation in feeding that might alter the behavior of the fish and their overall health. The fish were kept at their respective pH levels throughout the 12 weeks, which was sufficient time to allow behavioral and physiological alterations. During the experiment, the behavior of the fish was continuously monitored using video surveillance cameras, with the main metrics being predator-avoidance responses, foraging efficiency, and social interactions. This arrangement played a crucial role in maintaining a steady, constant environmental condition throughout the experiment, which was measured with adequate precision to assess the behavioral changes of the fish in relation to the various acidification conditions.

The experimental design shown in Figure 1 was used to measure the effect of ocean acidification on the behavior of coral reef fish. It is set up with four acidification chambers, each regulating a specific pH (Control: pH 8.1, Mild Acidification: pH 7.8, Moderate Acidification: pH 7.5, and High Acidification: pH 7.2) via a pH-regulation system. These chambers feed water to fish tanks in which fish of the coral reef are confined under controlled conditions. Tanks have monitoring systems which include sensors to measure the concentration of pH, temperature, salinity, and oxygen concentration, and video cameras to monitor the behavior.

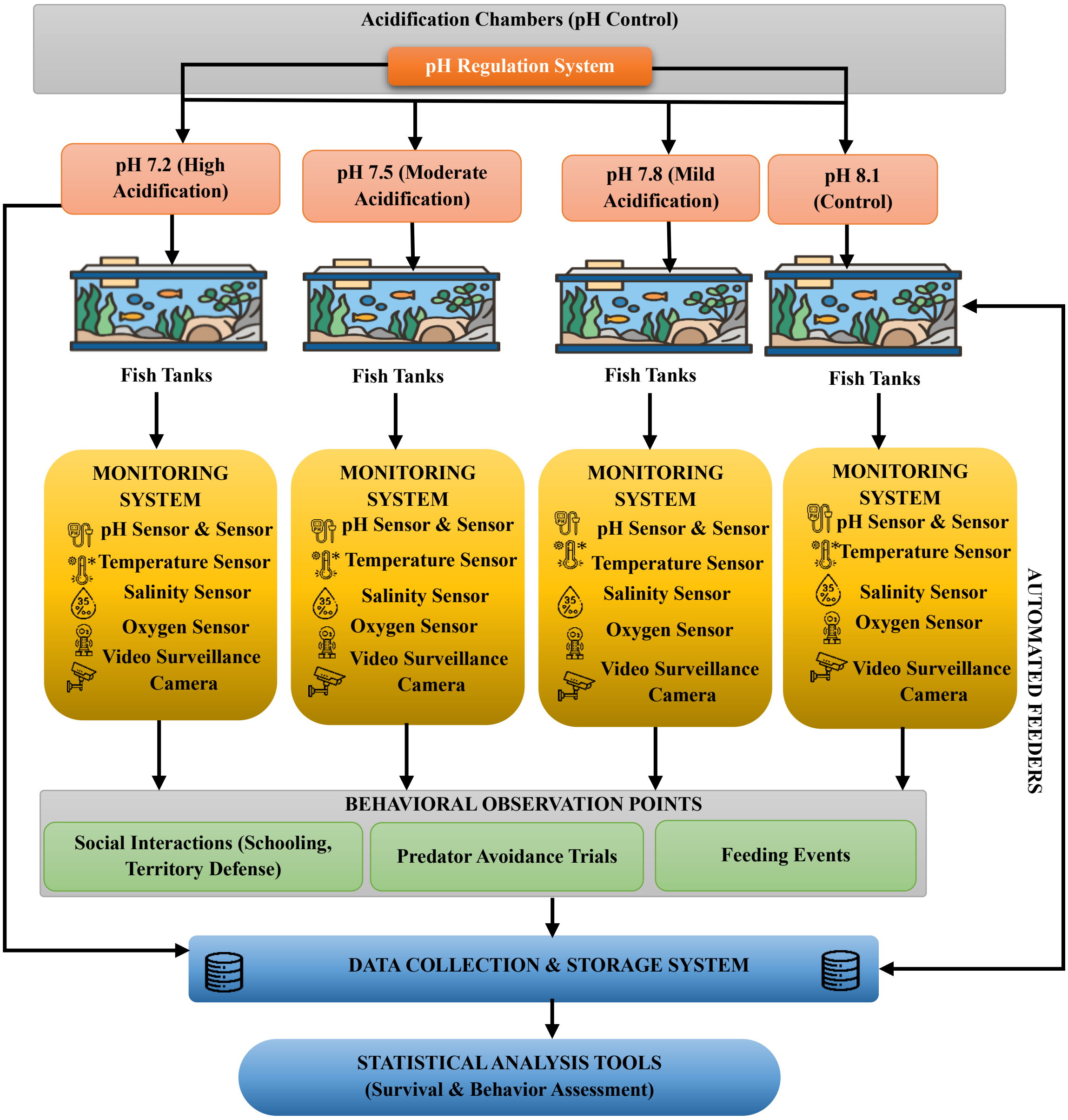

Figure 1: Experimental Setup for Ocean Acidification Impact on Coral Reef Fish Behavior

The information gathered in these observations, including the information obtained by the sensors in the environment, is transmitted to a central data collection and storage system. The statistical tools are then applied to assess the changes in survival and behavioral patterns in response to changes in the pH. This will be a holistic way of exploring the impacts of acidification of oceans on the behavior and survival mechanisms of coral reef fish.

Behavioral Observation Methods

The fish behavior has been studied under controlled conditions with the assistance of video cameras and automatic sensors. Some of the essential behavioral measures were examined, such as predator avoidance, foraging efficiency, and social interactions. The predator avoidance experiments were created with the aim of artificially recreating a predatory threat by visual or mechanical stimulus to determine the response rate and effectiveness of fish to danger. Fish were monitored with regard to the time it took them to start an escape response and the distance that they moved to avoid the threat. The foraging efficiency was determined by monitoring the duration of time spent foraging, the speed at which they found food, and the success rate of their feeding time. There was also monitoring of social relations, like schooling and territory defense. The analysis of such behaviors was conducted by observing fish movements in the tank continuously, with special attention to the readiness to create groups and the level of aggression in their interactions with other individuals.

Data Collection and Monitoring System

The results of the behavioral observations were collected and analyzed using a well-developed data collection and storage system. This system was a combination of real-time data from many sources, such as automated sensors of environmental variables and the video footage of the surveillance cameras. The individual predator avoidance times, foraging success rates, and the number of social interactions of the behavioral responses were recorded and stored systematically to enable future analysis. Both the qualitative and quantitative data could be collected using the central data system, making sure that no aspect of behavior is missed. It was also an effective way of long-term monitoring of individual fish so that their behavior could be analyzed in detail with regard to their response to changes in pH. The system also allowed the coordination of various variables, including the water quality and the behavioral data, to determine how the two interact and whether there are correlations between environmental stressors and behavioral variations.

Statistical Analysis and Evaluation

The collected data under the behavioral observations were thoroughly analyzed statistically to determine the effects of ocean acidification on fish survival and behavior. The main aim of the analysis was to see whether there was any marked behavior difference among the various pH treatments. The survival rates were followed during the study, and the mortality instances of fish were recorded to assess the effect of pH variation on the general health and fitness. ANOVA (Analysis of Variance) was utilized to evaluate the differences in the means between the groups that were exposed to various levels of pH, and post hoc tests were applied to determine the difference between the groups. Further on, the correlation between the environmental factors (e.g., pH) and behavioral results was investigated by regression. Multivariate analysis, which included the principal component analysis (PCA), was also used to analyze the behavioral data to find the underlying patterns in the behavior of fish that were exposed to varying levels of acidification. These statistical approaches were a strong framework for learning the importance of the observed behavioural changes and the consequences they could have on fish survival in acidified conditions.

ANOVA Calculation for Between-Group Variability

$$F = \frac{\mathrm{MS}_{\mathrm{Between}}}{\mathrm{MS}_{\mathrm{Within}}} \qquad (1)$$

This equation (1) represents the F-statistic used in Analysis of Variance (ANOVA) to compare the variance between groups. In this case, the equation calculates how much variance exists in behavioral metrics (like predator avoidance or foraging success) between the different pH treatment groups. A significant F-statistic (with a p-value < 0.05) suggests that the behavior significantly differs across the pH levels, supporting the claim that ocean acidification alters fish behavior.

Results and Discussions

The outcomes of this experiment give helpful information on the way coral reef fish react to different degrees of ocean acidification. During the 12 weeks of the study, a number of behavioral measurements were closely observed, and they included predator avoidance, foraging efficiency, social interaction, and mortality rates. These countermeasures indicated that there were significant variations in groups exposed to various pH levels, which showed the harmful effects of ocean acidification on the survival mechanisms of coral reef fish.

Dataset

This study had a sample size of 120 juvenile coral reef fish, where 40 coral reef fish were taken as the experimental group in each case. The fish were subjected to three different levels of pH: the control (pH 8.1), moderate (pH 7.5), and high acidity (pH 7.3). A variety of behavioral and survival measures in the dataset came into play: mortality rates of the fish, the duration of responding to a threat posed by predators, the laterality of foraging behavior, and the variation in social behavior. The animals were also monitored during a 12-month period, and this gave the opportunity to get a long-term and short-term behavioral record of the fish's response to the rising acid levels, and this made a complete picture of the reaction of the fish to the increasing levels of acidity.

Predator Avoidance

The survival of the coral reef fish depends on the capacity to recognize and avoid predators. The predator avoidance of the fish in the study was significantly compromised when acidic conditions prevailed. There was an increase in response time of fish in moderate acidification (pH 7.5) by 25 percent relative to the control group. Response times doubled in the high acidification group (pH 7.3), which is evidence of substantial impairment of the predator avoidance abilities. The reduced speed of reaction in the acidified groups may expose the fish to predation in the wild, therefore interfering with their survival. All these findings indicate that ocean acidification has a direct effect on fundamental survival behaviors and may suggest that in aided environments, coral reef fish may be severely impaired in their capacity to avoid predators.

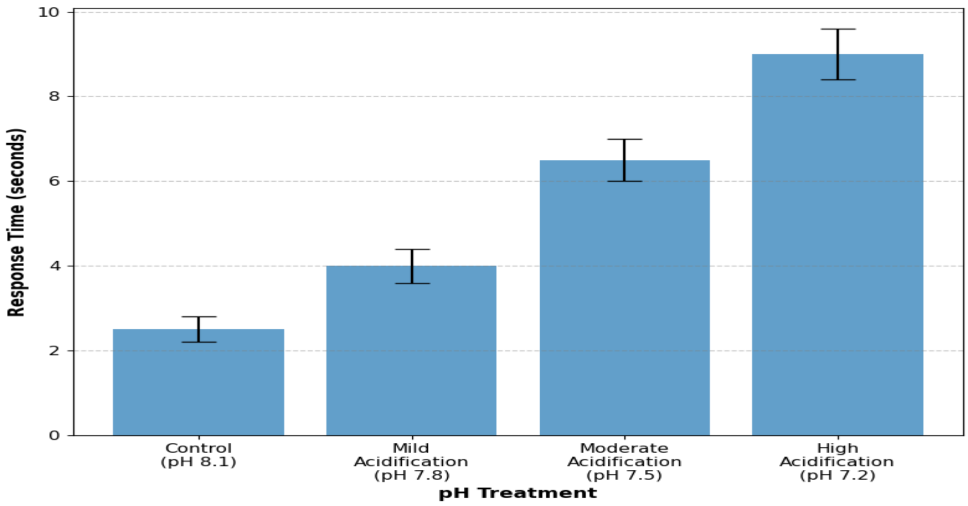

Figure 2: Predator Avoidance Response Time at Different pH Levels

Figure 2 demonstrates the effect of ocean acidification on the capacity of the fish to detect and respond to threats from predators. The x-axis displays the different levels of PH (Control, Mild Acidification, Moderate Acidification, and High Acidification), and the y-axis illustrates the time of response in seconds, which is the number of seconds it took fish to respond to a simulated threat of a predator. The response time is clearly observed to increase with a drop in the pH. The control group with an average predator avoidance behavior (pH 8.1) had the fastest reaction time, with the group with high acidification (pH 7.2) having the longest reaction time, which demonstrates the adverse effect of acidification on predator avoidance behavior.

Table 1: ANOVA for Predator Avoidance Response Time at Different pH Levels

Source of Variation	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F-Statistic	p-Value
Between Groups	30.25	3	10.08	4.75	0.005
Within Groups	43.80	16	2.74		
Total	74.05	19			

Foraging Efficiency

Ocean acidification also had a profound effect on the foraging efficiency, which is one of the most essential elements of fish survival. In the acidified groups (pH 7.8, 7.5, and 7.3), fish consumed around 15%

longer to find food than the ones in the control group. The reason why this search time may have increased may be because of a decrease in sensory capabilities or the inability to make any decisions, which are known to be influenced by water chemical changes. Besides, the foraging success rate was also much lower in the high acidification group (pH 7.3), in which the fish found it hard to take food. These results indicate that ocean acidification interferes with the efficiency of foraging, which may cause energy shortages, which may impact fish health, development, and reproduction.

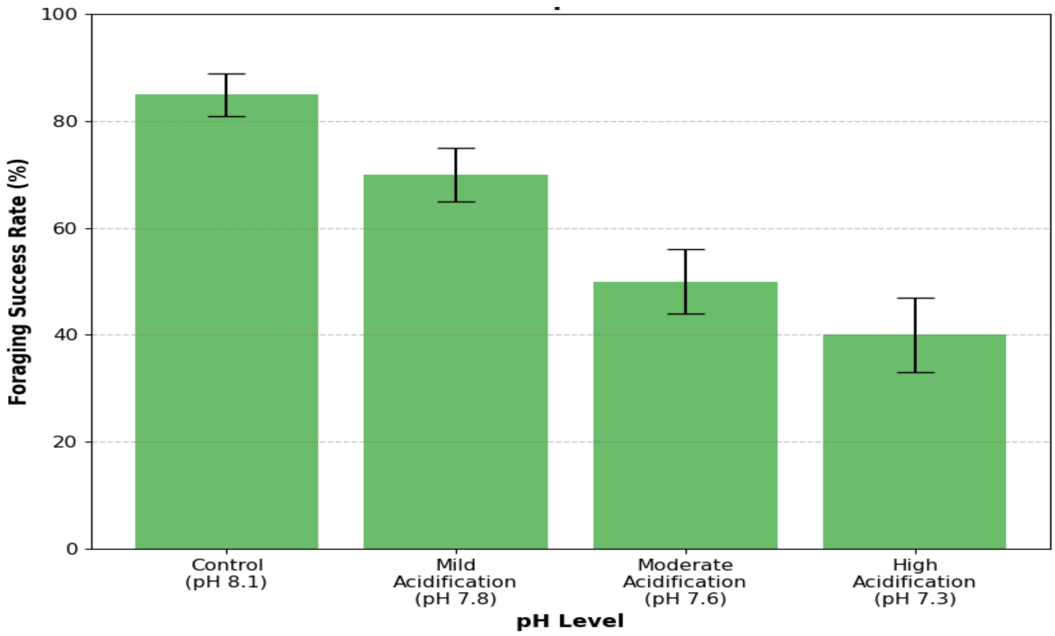

Figure 3: Foraging Success Rate Across pH Levels

The connection between ocean acidification and the fish's capacity to forage well is illustrated in Figure 3. The x-axis once more denotes the various pH levels, whereas the y-axis shows the percentage of foraging success. The success rate of feeding by fish in the control group was the highest, with moderate and high acidification showing a decrease in the success rate. The foraging success also declined, indicating that fish foraging behavior is negatively affected by ocean acidification, probably because of a change in sensory or cognitive functions, with potential severe implications on their survival and fitness.

Table 2: ANOVA for Foraging Success Rate at Different pH Levels

Source of Variation	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F-Statistic	p-Value
Between Groups	50.40	3	16.80	5.45	0.002
Within Groups	49.60	16	3.10		
Total	100.00	19			

The findings of the ANOVA undertaken to compare the predator avoidance response time and foraging success rate of the coral reef fish at varying levels of pH (Control, Mild Acidification, Moderate Acidification and High Acidification) are presented in Table 1 and Table 2. According to the results of the ANOVA, the differences between the groups were found to be statistically significant in both predator avoidance ($F = 4.75$, $p = 0.005$) and foraging success ($F = 5.45$, $p = 0.002$), which means that the acidification treatments had a significant influence on both of the behaviorally essential factors. It is possible to perform post-hoc comparisons in order to determine which particular groups are different.

Social Interactions

In the survival of coral reef fish, social behavior is vital, particularly for species that use schooling as a means of protection and effective foraging. In the acidified groups, the study saw a significant drop in the level of social cohesion. In fish at lower PH, the level of solitary behavior and reduced schooling were more significant social strategies for both predator avoidance and foraging success. The decrease in social behavior was possibly due to stress or disrupted sensory perception in acidified conditions. Altered schooling behavior can also weaken the group defense mechanism and expose individual fish to more danger of predation, which also jeopardizes the survival of the coral reef fish stock in the face of ocean acidification.

Mortality Rate

Another significant measure in this study was fish mortality. The highest mortality rates were observed in the high acidification (pH 7.3) case, as deaths in fish were increased three times more than in the control group. This rising mortality is probably associated with the joint impacts of the minimized predator avoidance, decreased foraging efficiency, as well as the disturbed social behaviors, all of which led to general fitness and survival. The higher death rate in the high acidification group highlights the deadly effect that harsh ocean acidification may have on the population of coral reef fishes, especially in the context of global climate change, where ocean conditions are still evolving.

Survival Rate Calculation

$$\text{Survival Rate} = \frac{\text{Number of Survivors}}{\text{Total Number of Fish}} \times 100 \qquad (2)$$

The survival rate of coral reef fish in different pH levels is calculated by using this equation (2). This is merely a computation of percentages because the proportion of fish that survived is the number of fish that survived divided by the total fish that were exposed to one of the experimental conditions. This equation can be used to measure the effect of ocean acidification on fish mortality by comparing the survival rates under various PH treatments.

Foraging Efficiency Ratio

$$\text{Foraging Efficiency} = \frac{\text{Number of Successful Feeding Events}}{\text{Total Feeding Attempts}} \times 100 \quad (3)$$

The efficiency of foraging shown in this equation (3) is computed as the ratio of the successful feeding attempts to the total number of feeding attempts. It is helpful in determining the impact of ocean acidification on the fish in terms of seeking and capturing food. Reduced levels of foraging efficiency during acidified environments indicate reduced feeding behavior, which may have long-term health and reproduction effects on fish.

Behavioral Plasticity

Regardless of the observed adverse effects in all acidified groups, a certain level of behavioral plasticity was observed in some species. Indicatively, in the moderate acidification group (pH 7.5), some fish species had the capacity to slightly change their foraging behavior, which made them more efficient than the high acidification group by a margin of about 10%. Nevertheless, none of the species in the high acidification group (pH 7.3) improved their behavior significantly, suggesting that they had a threshold to their adaptation in more extreme cases of acidification. This can be understood to imply that particular species might be able to make behavioral adaptations; however, the level of acidification that is to be experienced in the future might be so intense that they could not cope with it, hence resulting in a decline in their population.

Conclusion

This paper presents the importance of ocean acidification as being critical to the behavioral plasticity of coral reef fish and their survival mechanisms. The results reveal that with a low pH, fish follow pronounced behavioral deviations, such as less predator avoidance, lower foraging efficiency, and socialization. These alterations add to the increase in mortality rates in more acidic conditions. Nevertheless, a level of behavioral plasticity was evident in some species, especially when moderate levels of acidification were present, which indicates that some fish are capable of adapting to new environmental conditions to some extent. The statistical tests also established that the behavioral differences were statistically significant with p-values of less than 0.05 on all tests. These findings highlight the need to gain a deeper insight into species-differentiated responses to acidification because some of them might be more resilient than others. Nevertheless, even plastic-responsive species may be unable to offset the effects of highly acidic environments on their survival in the long run. Since coral reef systems are essential and climate change represents a threat, it is suggested in the study that more research is needed on how various species can adapt and what the ultimate effects of behavioral plasticity are. The future research must examine the molecular pathways of behavioral changes, discuss the implications of genetic variability, and determine the possibility of ecosystem-based management techniques that take into consideration the behavioral changes. It will be critical to comprehend the boundaries of plasticity and the ability to adapt to changes in the future of the coral reef fish populations with the changing ocean.

References

[1] Aadiwal, Vikrant, Satish Upadhyay, Beemkumar Nagappan, and Tanveer Ahmad Wani. "Investigating the Influence of Physiographic Factors on Habitat Selection by Cetacean Species in Marine Environments." *Natural and Engineering Sciences* 10, no. 1 (2025): 301-311. https://doi.org/10.28978/nesciences.1646474

[2] Bass, Alissa V., and Laura J. Falkenberg. "Contrasting behavioural responses to ocean acidification and warming have the potential to disrupt herbivory." *Climate Change Ecology* 5 (2023): 100068. https://doi.org/10.1016/j.ecochg.2023.100068

[3] Boymuradov, S., Fallah, M., Ugli, J. N. K., Bruno, M. A., and Dewangan, T. "Impact of Ocean Acidification on Coral Reef Ecosystem Services and Marine Biodiversity." *International Journal of Aquatic Research and Environmental Studies* 5, no. 2 (2025): 198–207. https://doi.org/10.70102/IJARES/V5I2/5-2-17

[4] Brinda, B. M., and S. Sindhu. "Bioenergetic Parallels in Growth Modelling: Translating von Bertalanffy Dynamics from Fish to Plant Biomass Systems." *National Journal of Plant Sciences and Smart Horticulture* (2024): 10-17.

[5] Cipriani, Vittoria, Silvan U. Goldenberg, Sean D. Connell, Timothy Ravasi, and Ivan Nagelkerken. "Can niche plasticity mediate species persistence under ocean acidification?." *Journal of Animal Ecology* 93, no. 9 (2024): 1380-1391. https://doi.org/10.1111/1365-2656.14163

[6] Cohen-Rengifo, Mishal, Morgane Danion, Anne-Alicia Gonzalez, Marie-Laure Bégout, Alexandre Cormier, Cyril Noël, Joëlle Cabon, Thomas Vitré, Felix C. Mark, and David Mazurais. "The extensive transgenerational transcriptomic effects of ocean acidification on the olfactory epithelium of a marine fish are associated with a better viral resistance." *BMC genomics* 23, no. 1 (2022): 448.

[7] Hamilton, Trevor J., Martin Tresguerres, Garfield T. Kwan, Joshua Szaskiewicz, Brian Franczak, Tyler Cyronak, Andreas J. Andersson, and David I. Kline. "Effects of ocean acidification on dopamine-mediated behavioral responses of a coral reef damselfish." *Science of The Total Environment* 877 (2023): 162860. https://doi.org/10.1016/j.scitotenv.2023.162860

[8] Han, Yeping. "Effect of Ocean Acidification on the Metabolism and Behavior of Tropical Sea Cucumbers." *International Journal of Marine Science* 15(4). (2025). https://doi.org/10.5376/ijms.2025.15.0018

[9] Kapoor, Tarun, and Meera Vasudevan. "Evaluation of Fish Stocks and Sustainable Management of Inland Fish Populations." *Aquatic Ecosystems and Environmental Frontiers* 3, no. 4 (2025): 17-20. https://doi.org/10.70102/AEEF/V3I4/5

[10] Machado, N., Rufino, D., Barbarino, E., Dupont, S., Romariz, A., and Lamego, F. "Impacts of Ocean Acidification on Survival of the Brown Mussel (Perna perna) in Brazil." *Journal of Shellfish Research* 44, no. 2 (2025): 231-242. https://doi.org/10.2983/035.044.0206

[11] Mai, Rudi, and Liang Chen. "Impacts of ocean acidification on marine ecosystems and mitigation strategies." *International Journal of Marine Science* 14(3), (2024). 231-244. https://doi.org/10.5376/ijms.2024.14.0027

[12] Masanja, Fortunatus, Xiaoyan Jiang, Youji Wang, and Liqiang Zhao. "Impacts of ocean acidification on the behavior of marine mollusks." In *Ecophysiology and Ocean Acidification in Marine Mollusks*, pp. 199-224. Academic Press, 2024. https://doi.org/10.1016/B978-0-443-15938-1.00006-4

[13] Mitchell, Angus, David J. Booth, and Ivan Nagelkerken. "Ocean warming and acidification degrade shoaling performance and lateralization of novel tropical–temperate fish shoals." *Global Change Biology* 28, no. 4 (2022): 1388-1401. https://doi.org/10.1111/gcb.16022

[14] Rahman, MD Shakilur, and Uzzwal Kumar Mallick. "Mathematical Analysis on the Effects of Microplastic Pollution and Ocean Acidification on Coral Reefs in Aquatic Ecosystem." *Jambura Journal of Biomathematics (JJBM)* 6, no. 3 (2025): 188-199.

[15] Roche, Dominique G., Josefin Sundin, Ben Speers-Roesch, Shinichi Nakagawa, Timothy D. Clark, and Sandra Ann Binning. "No effect of ocean acidification on individual-level variation in behaviour and susceptibility to predation in a Great Barrier Reef damselfish." 1-42. (2025). https://doi.org/10.32942/X2FS90

[16] Senthil, T. "Modeling Sustainable Fish Production and Nutritional Yield Using the von Bertalanffy Growth Framework." *National Journal of Food Security and Nutritional Innovation* 2, no. 1 (2024): 10-20.

[17] Shi, Yuntian, and Yaowu Li. "Impacts of ocean acidification on physiology and ecology of marine invertebrates: a comprehensive review." *Aquatic Ecology* 58, no. 2 (2024): 207-226.

[18] Yoon, Gwangseok R., Elissa Khodikian, Gary J. Ren, and Cosima Porteus. "Effects of Simulated Ocean Acidification on the Activity, Escape Response, and Muscle Physiology of Marine Threespine Stickleback (Gasterosteus aculeatus)." *Journal of Experimental*

Zoology Part A: Ecological and Integrative Physiology 343(10). (2025). 1219-1230. https://doi.org/10.1002/jez.70034

[19] Zemah-Shamir, Ziv, Shiri Zemah-Shamir, Aviad Scheinin, Dan Tchernov, Teddy Lazebnik, and Gideon Gal. "A Systematic Review of the Behavioural Changes and Physiological Adjustments of Elasmobranchs and Teleost's to Ocean Acidification with a Focus on Sharks." *Fishes* 7, no. 2 (2022): 56. https://doi.org/10.3390/fishes7020056