DOI: 10.54254/2753-8818/81/2025.21270

How Does Ocean Acidification Influence on Sharks

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Abstract: Ocean acidification, primarily driven by increased CO_2 emissions, poses a significant threat to marine ecosystems, particularly affecting the developmental stages and survival rates of various shark species. Current research on ocean acidification's impacts on sharks is limited, often focusing narrowly on isolated species or specific environmental conditions, leaving a gap in our comprehensive understanding of these effects. This study aims to address this gap by examining the impact of ocean acidification on the embryonic development, hatching success, growth rate, and physiological behavior of juvenile small-spotted catsharks under projected future acidity scenarios. Additionally, this study identifies the limitations of existing research and proposes directions for future research to better understand these effects. These findings highlight the detrimental effects of ocean acidification on shark populations, providing essential data that underscores the urgent need for conservation efforts. By advancing knowledge on how acidification impacts shark viability, this study contributes to the broader understanding required for developing effective management and protection strategies for vulnerable marine species.

Keywords: Ocean acidification, sharks' embryo, retarding sharks' development.

1. Introduction

Over the past two centuries, vast amounts of greenhouse gases have been released into the atmosphere as the Industrial Revolution and widespread fossil fuel usage have progressed [1]. This increase in greenhouse gas emissions, particularly carbon dioxide (CO_2), has led to significant and rapid shifts in the Earth's climate system, with CO_2 concentrations in the atmosphere rising drastically [2]. Beyond global warming, this increase has also triggered widespread ocean acidification, as approximately one-third of anthropogenic CO_2 emissions are absorbed by seawater, altering the carbonate chemistry of the ocean [3]. In the past fifty years alone, the oceans have absorbed between 24% and 33% of all artificial CO_2 emissions [4]. While this process has played a role in moderating global warming, it has led to a measurable drop in seawater pH, affecting the chemical equilibrium of carbonate ions in seawater, which is crucial to many marine organisms.

The consequences of ocean acidification extend beyond basic water chemistry, posing significant physiological and ecological challenges to marine life. Acidification's impacts are particularly harmful to organisms that rely on calcium carbonate for their skeletal or shell structures, including coral, shellfish, and some plankton species, which face challenges in maintaining their calcium carbonate structures in low-pH environments [5]. The ramifications of this are far-reaching; as foundational species struggle, entire marine ecosystems and food webs risk disruption, potentially

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reducing biodiversity and threatening ecosystem stability (Doney, 2009). Ocean acidification also impacts the ocean's carbonate system and essential nutrient cycles, such as those involving carbon, nitrogen, and phosphorus. Changes in these cycles can impair marine ecosystem productivity, with negative cascading effects up the food chain, ultimately impacting apex predators like sharks [6].

While many studies have focused on the impacts of acidification on calcifying organisms, less attention has been given to the potential effects on cartilaginous fish like sharks. As apex predators, sharks play a critical role in maintaining ecological balance within marine ecosystems. Ocean acidification could impact sharks at various life stages, especially in their embryonic and juvenile phases, which are likely highly sensitive to changes in ambient chemistry. Given their extended embryonic development, during which they rely on the yolk sac for nutrition, sharks may be particularly vulnerable to changes in pH levels. Existing studies indicate potential risks: Di Santo (2015) observed that acidified conditions impaired the growth and metabolism of brown-banded bamboo shark embryos, while Murray et al. found that high temperatures combined with low pH significantly disrupted the embryonic development and increased mortality rates in small-spotted catsharks (Scyliorhinus canicula) [7]. However, there remains a lack of comprehensive research on acidification's effects on shark physiology, behavior, and ecology, highlighting a critical gap in our understanding.

By providing a comprehensive analysis of these key developmental and physiological traits under projected future acidity scenarios, this work enhances our understanding of how ocean acidification impacts shark populations. The insights gained are crucial for developing effective conservation strategies, ultimately supporting the protection of marine biodiversity in an acidifying ocean.

2. Literature Review

2.1. The Role of Sharks in Marine Ecosystems

Sharks play a vital role in maintaining the balance and health of marine ecosystems; as apex predators, sharks regulate population sizes at the next level of the food chain; this predatory role helps to prevent the overpopulation of certain species that would otherwise lead to habitat degradation and destabilization of the entire ecosystem [8]. Sharks contribute to prey populations' well-being and genetic diversity by hunting down weak and old individuals. The act ensures that only the healthy members of the prey population survive, thus fostering biodiversity, which propels stability within an ecosystem. In a similar incident during the early 20th century at Yellowstone Forest Park, wolves were eliminated in the U.S. federally protected area because of red deer. The absence of wolves resulted in an abnormal increase in the red deer population because they had no natural predators, leading to massive deaths among deer due to over-exploitation and limited food [9]. After this event, President Bill Clinton allowed wolf re-introduction into Yellowstone National Park in 1995. The presence of wolves effectively regulated deer populations and behavior, reducing their impact on specific sites. Ultimately, this practice protected the ecosystem and allowed plants to grow back. What happened in Yellowstone Forest Park illustrates the critical role of apex predators in maintaining ecological balance. Sharks fundamentally affect the structure and function of marine communities in marine ecosystems [10]. Sharks fundamentally affect the structure and function of marine communities in marine ecosystems [11]. Most sharks occupy a high position in the deep-sea food chain.

A study showed that when shark populations declined, herbivorous fish populations spiked, leading to the degradation of coral reefs, suggesting that sharks play an irreplaceable role in maintaining the health of coral reef ecosystems. That's because in areas where sharks are present, herbivorous fish tend to avoid open areas to reduce predation risk. This behavioral change can reduce algal pressure in a given area and help maintain the stability of corals and other vital habitats [12].

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The ecological effects of this predatory behavior suggest that sharks not only affect ecosystems through direct predation but also indirectly through influencing the behavioral patterns of their prey, which can profoundly affect ecosystem health and diversity.

Ocean acidification is undoubtedly a direct threat to sharks. As ocean acidification continues, long-term ecosystem-level impacts are becoming apparent. The decline of significant predators like sharks disrupts the balance of the marine food web, leading to a ripple effect throughout the ecosystem [13]. These studies emphasize the importance of sharks as predators and as essential components of broader ecological processes that sustain marine biodiversity and affect the structure and function of entire marine ecosystems. The studies suggest that shark populations should be protected to maintain the species and ensure the health and sustainability of the marine ecosystem.

2.2. Impacts of Ocean Acidification on Sharks

Ocean acidification, resulting from increased atmospheric CO_2 absorption by seawater, presents unique challenges to marine organisms, with particularly concerning effects on sharks due to their physiological and ecological roles. As apex predators, sharks are essential in maintaining the balance of marine ecosystems, and disruptions to their health and behavior could have cascading impacts throughout the food web. Research has identified three primary areas where acidification affects sharks: embryonic development and juvenile growth, olfactory sensitivity, and foraging efficiency alongside energy metabolism.

2.2.1. Impacting Embryonic Development and Juvenile Shark Growth

Shark embryos are highly susceptible to environmental changes, particularly in acidified conditions that alter nutrient absorption, increase metabolic demands, and slow overall development. Studies on the small-spotted catshark (Scyliorhinus canicula), an oviparous species ideal for laboratory studies due to its manageable size and continuous reproductive cycle, show that acidified environments delay yolk consumption, reducing the efficiency of nutrient absorption necessary for growth. Coulon's research observed that embryos in highly acidified environments demonstrated significantly lower growth rates and extended developmental durations in later stages, likely due to increased fragility of the eggshells and greater susceptibility to environmental stress, infection, and breakage. Survival rates in these extreme conditions were alarmingly low, with only 11% of embryos surviving in the most acidified environments, compared to substantially higher rates in control groups [14].

Moreover, high-acidification conditions disrupt normal growth and introduce malformations in critical organs, such as the heart and gills, which play essential roles in circulation and respiration. Di Santo (2015) demonstrated that in brown-banded bamboo shark (Chiloscyllium punctatum) embryos, the reduced pH slowed growth, increased metabolic energy requirements, and heightened the likelihood of abnormalities, particularly in the cardiovascular and skeletal systems [15].These malformations can weaken the embryo's viability post-hatching, as compromised heart function may hinder blood circulation, and underdeveloped gills may limit oxygen uptake. The combined effects of delayed development, reduced hatching success, and increased embryonic mortality highlight the risks posed by ocean acidification, potentially threatening shark populations by undermining the survival rates of juvenile sharks from birth.

2.2.2. Weakened Sense of Smell

Sharks depend heavily on their acute sense of smell to locate prey, particularly in low-light or murky environments. This olfactory sensitivity allows them to detect chemical cues from prey over long distances, making it a crucial adaptation for hunting and survival. However, ocean acidification has been shown to impair olfactory function in sharks, leading to decreased sensitivity and response to

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food-related odors. Munday et al. (2010) demonstrated that fish species, including sharks, experience diminished olfactory acuity in acidified conditions, which can weaken their ability to track prey effectively. For example, juvenile Jackson's sharks (**Heterodontus portusjacksoni**) exhibited slower response times to prey scents and reduced foraging success in low-pH environments [16]. The study found that acidification hindered the sharks' olfactory receptors, which likely disrupts the chemical cues critical for locating food, thereby impacting their hunting efficiency.

In addition, experimental results indicate that sharks in high-CO_2conditions take up to four times longer to detect prey compared to those in normal conditions. When exposed to elevated temperatures alongside acidification, their response time was reduced by one-third, demonstrating that temperature can somewhat counterbalance the effects of acidification on olfactory impairment. Dixson et al. (2015) further supported these findings in smooth-hound sharks (**Mustelus canis**), showing that those exposed to elevated CO_2levels displayed weaker responses to food stimuli, reduced feeding aggression, and less attraction to water currents containing food odors. This decline in olfactory function could have severe consequences for shark populations, as reduced hunting efficiency may lead to lower growth rates, less reproductive success, and greater difficulty competing for resources in their natural habitat.

2.2.3. Changes in Foraging Efficiency and Energy Metabolism

Ocean acidification, combined with temperature increases, has significant implications for the energy metabolism and foraging efficiency of sharks. Low-pH environments increase the metabolic cost required to maintain physiological homeostasis, which diverts energy away from growth and reduces foraging effectiveness. Pistevos et al. (2015) reported that juvenile Jackson's sharks under acidified conditions exhibited reduced foraging efficiency, as the energy needed to adapt to acidified water limited the resources available for hunting behaviors. Sharks in acidified waters demonstrated lower prey capture rates, likely due to the additional metabolic load reducing their predatory stamina and ability to sustain active hunting.

Similarly, Pegado et al. (2020) found that sharks exposed to high CO_2 concentrations showed less interest in food stimuli, lower aggression levels, and decreased prey detection efficiency [17]. Growth rates of juvenile sharks kept in high-CO_2mesocosms were also significantly lower than those in the control group, indicating that acidification impedes not only the behavior but also the physical development of sharks. The study observed that energy allocation shifted primarily toward maintaining basic physiological functions rather than supporting active foraging and growth, which may explain the reduced hunting frequency, delayed feeding behaviors, and lower success in prey capture observed in acidified conditions.

These metabolic and behavioral changes could have profound impacts on shark populations. Reduced foraging efficiency over time can lead to slower growth rates and diminished reproductive success, undermining population stability and potentially reducing the presence of sharks as apex predators. Given sharks' critical role in regulating marine ecosystems, these disruptions may have far-reaching ecological consequences, such as unbalanced prey populations and shifts in species interactions, which could alter the entire food web. Ocean acidification thus not only endangers individual sharks but also threatens the broader ecological stability of marine environments where sharks serve as key regulators.

3. Limitations of Current Research

While the growing body of research on ocean acidification's impacts on sharks has helped lift some of the mystery surrounding this aspect, many limitations must be considered for a holistic approach. The first is that most researchers have carried out their studies under controlled laboratory conditions.

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Such an act may help capture all the complexities of actual marine environments. During these laboratory studies, researchers typically keep only a couple of variables (for example, pH and temperature) constant, failing to mimic other environmental factors available to sharks throughout their natural habitat. On the other hand, in real applications, the marine environment involves multiple salinity changes and contaminant presence as well as alterations in food web structure: these may compound the effects of acidification on sharks, but, to date, research does not capture such intricate interactions. Secondly, many of the studies conducted so far have been specific to certain shark species or life stages. Therefore, broader studies covering different species or life stages are essential. For example, while some studies have shown the effects of acidification on common species such as small spotted catsharks and brown-banded bamboo sharks, these results may apply specifically to a subset of shark species. The sensitivity of each species to environmental change varies, so researchers should conduct wide-ranging studies with more species diversity and ecological context to make more generalizable conclusions. This inclusive approach is necessary to fully understand the impacts that ocean acidification will have on sharks.

The lack of long-term data makes predicting the effects on shark populations and ecosystems easier. It presents a substantial challenge when developing and implementing conservation-based management strategies. This information is critical for practical conservation efforts. Moreover, the study's time scale is a notable limitation. Most of the experimental studies available have been over the short term, with a typical range of a few days to a few months. In contrast, ocean acidification takes place over the long term, and its cumulative effects on ecosystems and species might take several years, or even several decades, to become apparent. Geographic limitation of studies on ocean acidification. Most of the research has been in coastal northern hemisphere locations, with the tropics and polar regions receiving little attention. Our knowledge of how ocean acidification will impact sharks worldwide, as opposed to global distribution areas with vastly different environmental conditions and ecosystem dynamics. Including these regions in studies will be necessary to understand ocean acidification's global impacts on sharks. The chemistry, temperature, and structure of ocean basins are very different; therefore, future work should also focus more on these neglected regions if we want to understand this problem globally.

4. Conclusion

Overall, ocean acidification, an essential aspect of global climate change, has complex and far-reaching impacts on sharks and their ecosystems. Understanding these impacts is critical to protecting shark populations and maintaining the health of marine ecosystems. Future research should deepen the understanding of ocean acidification and provide scientific support for developing effective conservation strategies to address this global environmental challenge. For instance:

1. Interdisciplinary research: Combine biology, chemistry, and ecology to systematically analyze ocean acidification's comprehensive effects on sharks' early developmental stages. The search should further explore the impacts of acidification and temperature change on different shark species and formulate corresponding conservation policies to meet the challenges of climate change.

2. Long-term monitoring and conservation measures: Establish a long-term monitoring system to track the impacts of ocean acidification on shark populations in real time and formulate corresponding conservation measures to ensure the sustainable development of shark populations.

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