significant, long-lasting damage. Natural disasters-such as tsunamis, floods, and wildfires-can destroy habitats and alter ecosystem functions. Additionally, industrial accidents, oil spills, or chemical leaks introduce toxins into the air, water, and soil, while prolonged droughts deplete water resources, impacting both agriculture and natural water bodies (Hader et al., 2020; Cramer et al., 2018; Harun et al., 2021). Specific aquaculture uncertainties include harmful algal blooms (HABs), which produce toxins that affect aquatic organisms and pose significant public health risks through the food chain. Silt buildup, poor water quality, and fish escapes are also recognized as major challenges (Bondad-Reantaso et al., 2018; Luna et al., 2020). These risks involve genetic issues, climate change, habitat structural changes, and occupational hazards (Yang et al., 2020).

In closed aquaculture technologies, water quality is maintained with minimal exchange with natural waterways, reducing pollution, negative wildlife interactions, and the transfer of parasites or diseases. Improving aquaculture performance is essential to provide safe, nutritious food while minimizing the environmental footprint. This ecologically friendly approach increases production efficiency relative to the land, water, feed, and energy used (Richard Waite, 2014). India promotes carp polyculture as a sustainable production method based on ecological principles that maximize resource utilization. By stocking compatible species-including surface feeders, column feeders, bottom feeders, and plankton feeders-all available ecological niches within the pond are utilized efficiently. This ecological basis for sustainability is further enhanced by waste recycling and resource management through modern engineering approaches (Jana et al., 2000; Jana, 2003). Conversely, the destruction of mangrove swamps-which are ecologically sensitive nurseries-directly impacts coastal estuaries, fish migration, coral reefs, and seagrass beds, ultimately affecting marine biodiversity and the livelihoods of coastal communities.

4.2 Climate change and fisheries

Climate change significantly impacts aquaculture production through fluctuations in water temperature, sea-level rise, and increased disease prevalence. Implementing robust mitigation techniques and adaptation strategies is essential to address extreme climate variance, overcome severe disruptions, and adapt to evolving ecosystem dynamics for sustainable development (Shukla et al., 2019; Galapaththi et al., 2020). Developing climate resilience strategies-such as the adoption of Biofloc Technology (BFT) and Recirculating Aquaculture Systems (RAS) assists farmers and stakeholders in withstanding adverse environmental shifts. Furthermore, Integrated Multi-Trophic Aquaculture (IMTA), cage culture, monosex tilapia farming, and the cultivation of air-breathing fishes serve as critical components of climate-smart aquaculture. These management strategies resist environmental changes by combining mitigation and adaptation to protect threatened marine ecosystems and fisheries.

According to the United Nations Conference on Trade and Development (UNCTAD), global fishing fleets powered by fossil fuels, such as marine diesel, emit between 0.1% and 0.5% of global carbon emissions, totaling up to 159 million tons annually. Consequently, understanding the impact of climate change on fisheries management is vital for developing policies that emphasize practical water quality management. This includes regular monitoring of critical parameters such as pH, ammonia, and dissolved oxygen levels-and the implementation of efficient water circulation systems. Utilizing bio-filters to remove waste products and excess nutrients is essential for maintaining optimal water quality and reducing the overall environmental footprint of aquaculture operations in a changing climate.

4.3 Carrying capacity and production

Carrying capacity refers to the maximum population density of a species that a given environment can support indefinitely without causing irreversible damage to the ecosystem or the health of the cultured stock. This threshold ensures productivity can be sustained without deleterious effects on the surrounding aquatic environment (Chapman and Byron, 2018). Carrying capacity is evaluated throughout the site selection procedure, beginning with initial capability calculations and receiving particular emphasis during the establishment of aquaculture facilities. This process adheres to spatial and temporal dimensions by evaluating the complete range of available space before determining suitable locations (Weitzman and Filgueira, 2020).