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ASSESSMENT OF GLOBAL WARMING IMPACT ON AQUATIC ECOSYSTEMS: A STATE-OF-THE-ART PERSPECTIVE

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Abstract

The negative effects of global warming are well recognized globally by scientific communities and governments. Aquatic environments absorb approximately 93% of the excess heat generated by global warming. Aquatic ecosystems sustain fisheries and aquaculture, sectors which provide approximately 17% of animal protein for the global human population. It is imperative to identify the main challenges that will occur within these systems due to global warming, to mitigate the consequences. The aim of the present review is to describe the impact of global warming factors on aquatic ecosystems. The research articles revised within this paper are published in web of science core collection, with high impact factors. The main factors of global warming were identified as: increased water temperature, sea level rise and altered precipitation regime. Each factor was analysed and the influence on aquatic environments was described. The main conclusion of this paper is that global warming will disrupt fisheries and aquaculture activities, through degradation of aquatic ecosystems. Small-scale fishers and aquaculture earthen ponds will be most impacted, due to their geographical location and economic vulnerability.

***Key words**: global warming, sea level rise, aquatic ecosystems, fisheries, aquaculture.*

INTRODUCTION

Warming of the climate system is indubitable (FAO, 2018). Global warming is a direct result of human activity and it is manifested by the rise in global surface temperatures, caused by the increased emissions of carbon dioxide (CO_2) and other greenhouse gases (GHG) such as methane (CH_4) and nitrous oxide (N_2O) (Asakura, 2021; FAO, 2013; Poloczanska et al., 2013). GHG absorb heat and emit it back in the atmosphere as radiant energy, causing the greenhouse effect. The Intergovernmental Panel on Climate Change (IPCC) reported an increase in global average surface temperature, between the years 1880 and 2012, of approximately 0.9°C (Rotman, 2015; Mann et al., 2020). From the total additional heat generated by anthropogenic climate change only 1% is retained in the atmosphere and approximately 93% is absorbed by the global ocean (FAO, 2018). The identified factors of global warming include temperature changes, sea level rise, and altered precipitation regime (Figure 1) (Diop et al., 2018a). The negative effects of this phenomenon extend on aquatic ecosystems, biotic communities, and biodiversity, through loss of habitats (wetlands drainage), aquatic species displacement, loss, and redistribution (Asakura, 2021; Smale et al., 2021; Sunobe et al., 2014). As well, global warming determines extensive and fast sea ice melting, and therefore, a rise in sea levels, which will impact stock dynamics and fish harvest levels in the future (Jorgensen et al., 2020; Diop et al., 2018).

One of the main effects of global warming on fisheries sector is the geographical shifting of target aquatic species (Jorgensen et al., 2020). Several studies have emphasized the influence of global warming on fisheries and the ecological performance of aquatic ecosystems (Diop et al., 2018b; Garza-Gil et al., 2011; Steinmetz et al., 2008; Lehodey et al., 2006). For instance, Diop et al. (2018a) predicted in the future the total collapse of shrimp stocks in the French Guiana region, due to global warming. According to Handisyde et al. (2014), in case of aquaculture activities, the impact of global warming can be either direct (changes in water availability, temperature) or indirect (increased fishmeal costs and thus, increased aquaculture feed costs).

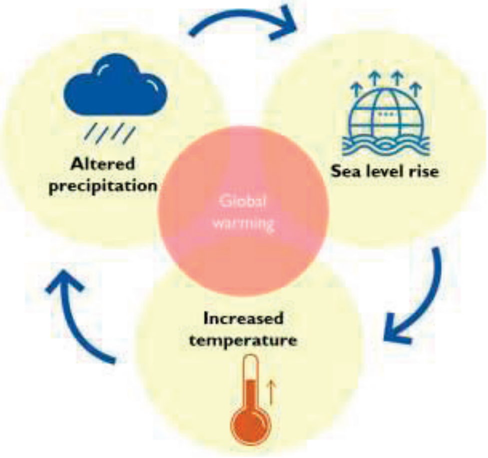

Figure 1. The factors of global warming

Aquatic ecosystems sustain fisheries and aquaculture, sectors which provide approximately 17% of animal protein for the global human population and in coastal areas it can reach even 70% (FAO, 2014). Therefore, it is important to identify the changes that will occur within these systems due to global warming. The influence of global warming on the aquatic environment is a matter of global interest and requires a thorough analysis which should correlate and compare the results of different studies published in peer-reviewed scientific journals (Ciugulea and Bica, 2016).

The aim of the present short review is to describe the impact of the global warming factors on aquatic ecosystems, in order to mitigate the negative effects.

MATERIALS AND METHODS

Increased water temperature

According to FAO (2013), sea surface temperature is expected to increase 0.7°C by 2035, 1.4°C by 2050 and 2.5°C by 2100. Water temperature is expected to manifest an upward tendency, with higher warming rates near the surface, especially in the first 100 m (FAO, 2013). Increasing water temperature can alter water quality, especially in the systems that receive high loads of anthropogenic effluents rich in nutrients and it can enhance eutrophic conditions by stimulating explosive macrophyte growth (Ficke et al., 2005; FAO, 2018). The increased temperature of water bodies leads to water stratification, which can have pronounced negative effects in freshwater systems compared to marine systems, due to shallowness and lower buffering capacity (FAO, 2018). Freshwater systems are more exposed to warming compared to marine ones, due to relatively shallow depths, susceptibility to atmospheric temperature change and an increase of 1.8°C is expected within these systems (FAO, 2018). It is expected that water stratification will be more pronounced in lotic and lentic ecosystem. The different density gradient between the upper and bottom water layer will prevent water mixing. Water mixing is important because the bottom layer contains minerals necessary for algae development, minerals that lack in the upper layer. Nevertheless, the light received from solar radiation and dissolved oxygen (DO) in the water upper layer stimulate photosynthesis of blue-green algae, which can fix nitrogen in nutrient-limited conditions. However, blue-green algae are inedible by most zooplankton species and planktivorous fish species (Ficke et al., 2005). Therefore, a shift in phytoplankton composition can pose a negative impact on fisheries productivity (Ficke et al., 2005). As well, blue-green algae produce alkaloids that are toxic to fish (Ficke et al., 2005). According to Handisyde et al. (2014), the impact of sea surface temperature changes on aquaculture includes: increase of harmful algal blooms that produce fish kills, decreased dissolved oxygen, increased diseases and parasites, change in the location and size of suitable range for target species, altered local ecosystems - competitors and predators, competition, parasitism and predation from exotic and invasive species.

Warming is more prominent in the Northern Hemisphere, especially the North Atlantic, compared to the rest of the globe (FAO, 2018). Negative effects of the rising water temperature include bleaching of corals, redistribution of the northern limit for subtropical and tropical fish species (Asakura, 2021; Wada, 2001).

According to Asakura (2021) the adaptation of tropical animals to temperate regions occurs in 5 stages as it follows: pseudo-population without overwintering (stage 1), pseudo-population with overwintering but no reproductive activity (stage 2), pseudo-population with overwintering and minor reproductive activity (stage 3), complete adaptation of tropical species to temperate environment (stage 4), genetic differentiation and speciation (stage 5). To escape water warming, fish will migrate poleward, phenomenon which will result in species invasion in the Artic, while Artic fish species will migrate further North, altering species composition (Hader and Barnes, 2019). In their study (Kaeriyama et al., 2014) pointed out that global warming decreased suitable areas of habitat for chum salmon in the North Pacific Ocean and loss of migration route to the Sea of Okhotsk. According to Ficke et al. (2005), for temperate fishes (such as carp, freshwater bream, pike, zander) a slight increase in water temperature could be beneficial due to the expansion of the growth season. However, the reproductive success of temperate fishes will be affected by global warming, because low overwinter temperatures are essential for inducing puberty and spawning success (Ficke et al., 2005). In their study, Simionov et al. (2020) pointed out a strong negative correlation between fish species diversity and water temperature. Thus, warming of aquatic ecosystems is associated to low fish diversity.

Another negative effect of rising water temperature is the decrease of DO levels, which will create and expand oxygen minimum zones (FAO, 2018). Oxygen solubility has an inverse relationship with water temperature (Ficke et al., 2005). For instance, at water temperature of 0°C the level of DO is 14.6 mg L^{-1} and at a water temperature of 25°C they DO level is 8.3 mg L^{-1}. The aerobic metabolic rate of most cold-blooded aquatic organisms increases with temperature, therefore global warming reduces oxygen supply in the water column and, at the same time, increases the biological oxygen demand of aquatic organisms (BOD) (Ficke et al., 2005). DO levels of 5 mg L^{-1} are acceptable for most aquatic organisms, however, if DO drops below 3 mg L^{-1} hypoxic conditions are present (Ficke et al., 2005). In aquaculture activities, hypoxic conditions can lead to reduced growth rates and reduced reproductive performance (Ficke et al., 2005).

It is expected that temperate and subarctic fish species will suffer high parasite infestation due to increased transmission opportunity. Higher water temperature during winter season allows parasite survival, and thus, increasing the potential of infection and multiple generations of parasites during a whole year (Ficke et al., 2005). In aquaculture systems, bacterial diseases such as furunculosis are positively associated to increased water temperature (Ficke et al., 2005). Also, it is important to mention that the toxicity of common pollutants such as heavy metals, organophosphates and ammonia increases with high levels of water temperature (Ficke et al., 2005). This phenomenon is related to increased gill ventilation at warmer temperatures, which results in high pollutant uptake (Ficke et al., 2005).

Sea level rise

Sea level rise (SLR) has been defined as one of the worst consequences of global warming (Kibria, 2016). According to FAO (2018), between the years 1901 and 2010, an upward tendency was registered in case of the average global sea level by 0.19 m, with an increased average of 3.1 mm per year. It is expected that by the year 2100 the global mean SLR could be as high as 1 m, if GHG levels continue to increase (Mills et al., 2020). SLR is generated primary by thermal expansion and secondly by melting of glaciers/ice caps (Kibria, 2016). The impact of SLR will expand on wetlands and its biodiversity, water resources, fisheries, and aquaculture (Kibria, 2016). The damage of SLR will affect wetlands included in Ramsar and World Heritage sites (Kibria, 2016). According to Kibria (2016), a 1 m SLR can cause approximately 25-46% loss of the world's coastal wetlands. The loss of biodiversity caused by SLR includes drowning of coral reefs, loss of breeding and nursery habitats.

Another potential negative effect is the infiltration of saline water in freshwater and brackish ecosystems, which can pose a threat to the aquatic biodiversity. Also, SLR is responsible for progressive salinization of freshwater resources (Hader and Barnes, 2019; Yang et al., 2020). The intrusion of salt can alter the physical properties of deltas and estuaries by increasing water stratification (Mills et al., 2020). Furthermore, according to Zak et al. (2021) the salinization of coastal wetlands enhances sulphate pollution, by increasing SO_4^{2-} concentrations, especially in peat-rich coastal regions.

The impact of SLR on aquaculture includes loss of areas available for aquaculture, loss of areas such as mangroves that provide protection from waves and fish nursery areas, severe flooding, salt intrusion into ground water (Handisyde et al., 2014).

Altered precipitation regime

The warming of the climate has significant implications for the hydrological cycle (FAO, 2018). Global warming tends to enhance the frequency and intensity of precipitation extremes (Li et al., 2021). Surface warming is directly linked with increase in rainfall due to the warming effect, which intensifies evaporation processes over the ocean and water body surfaces, thus increases the water-retention capacity of the atmosphere (Gbode et al., 2021). The rain-induced disasters are manifested through either floods or droughts (Li et al., 2021). Models indicate that zonal mean precipitation is very likely to increase in high latitudes and near the equator, and decrease in the subtropics (FAO, 2018). As well, in the Mediterranean basin and in the already arid zones, droughts are expected to be longer and more frequent, which will lead to reductions in river flows. Intense periods of draughts can lead to wetland drainage, which can expose large areas of SO_4^{2-} reservoirs (Zak et al., 2021). Following the flooding of these areas, due to intense precipitation, sulphate pollution is manifested in the water (Zak et al., 2021).

Changing precipitation alters the quantity, quality and seasonality of water resources (FAO, 2018). Changes in precipitation will substantially alter ecologically important attributes of flow regimes in many rivers and wetlands and exacerbate impacts from human water use in developed river basins (FAO, 2018). Events of droughts will impact aquaculture by inducing salinity changes in the technological water, reducing water quality, limiting water volume, reducing pond levels, altering and reducing freshwater supply (Handisyde et al., 2014). As well, the survival of certain fish species depends on rainfall and runoff from terrestrial landscape, to generate stream flows and the persistence of seasonal ponds (Hader and Barnes, 2019). For freshwater and estuarine ecosystems, changing rainfall patterns can influence water quality and salinity which can then influence the productivity and composition of phytoplankton and aquatic plant communities (Hader and Barnes, 2019).

Heavy rainfall events can lead to increased water turbidity (Bastaraud et al., 2020). In their study, Zhang et al. (2020) demonstrated that increased water turbidity affects the phytoplankton composition in Xiaoqing River. Change in the precipitation regime can influence fish disease prevalence. Increased precipitation was positively correlated with increased parasite (trematode metacercariae) abundance in freshwater fishes (Poulin, 2020). Another study conducted by Smederevac-Lalić et al. (2018) pointed out that high water turbidity, caused by extreme spring flooding, decreases the survival of pontic shad eggs and larvae. Nevertheless, the flooded land near rivers and streams, provide suitable spawning substrate, refuge against predators and high food availability for cyprinid fish species (Janac et al., 2010).

RESULTS AND DISCUSSIONS

It has been pointed out that mangroves can act as a cooling mechanism in coastal areas, due to their wet substrate and despite their large thermal acceptance (Diop et al., 2018a; Bin 2016). Thus, restoring mangrove surface can attenuate the negative effects of global warming. As well, mangrove forests, seagrass beds and marshes act as carbon sequesters, through their vegetation systems (Mcleod et al., 2011). These systems remove and keep carbon from the atmosphere with higher rates compared to the terrestrial systems (rainforests), due to their high productivity and sediments presence (Mcleod et al., 2011). Coastal wetlands provide flood and storm protection, waste assimilation, nutrient cycling functions (Kibria, 2016). To mitigate aquatic biodiversity loss, Saulnier-Talbot and Lavoie (2018) propose the use of anthropohydrocosms (anthropogenic aquatic ecosystems) such as reservoirs, farm ponds, drainage basins, park lakes, storm water ponds, stabilization ponds, artificial wetlands, canals, min void pit lakes, bomb crater ponds, bomb crater lakes etc. These types of anthropogenic aquatic ecosystem can substitute aquatic habitats loss due to global warming and provide new places for species development, reproduction and settlement.

CONCLUSIONS

The main conclusion of this paper is that global warming will disrupt fisheries and aquaculture activities, through degradation of aquatic ecosystems. It is most likely that small-scale fishers and aquaculture earthen ponds will be most impacted, due to their geographical location and economic vulnerability.

More studies such as long-term monitoring of aquatic ecosystems under global warming influence are needed, in order to generate mathematical predictions.

The present review can act as support material for identification of adaptation measurements by governments of coastal countries fighting global warming impact.

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