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INTERACTION BETWEEN AQUATIC BIVALVE SPECIES AND GLOBAL CLIMATE CHANGE

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ABSTRACT: Climate changes affect the bio-ecological characteristics of living things in aquatic ecosystems. It is the main factor in accelerating the geographical distribution of species, especially by triggering species invasions. Also, climate change is important as it increases the risk of infection between species. Bivalve species are among the important fishery species due to their high nutrient content, widespread distribution in aquatic ecosystems, rapid growth, and ecological and commercial values. Climate change and its effects have caused some invasive bivalve species, which can spread rapidly in aquatic environments, to be included in the list of biological pollutants due to their ecological and economic effects. In this review, the role of climate change in the growth performance, economic and ecological effects of bivalve organisms and the sustainable alternatives that can be applied at the solution point were evaluated.

Keywords: Global Warming, Mussel, Biological Invasion, Aquatic ecosystem.

1. INTRODUCTION

It is a fact that there are changes in climate systems as global average temperatures increase which is a result of increasing greenhouse gas emissions in the atmosphere. These changes have become one of the most important issues of our time and it requires urgent actions. Among the main causes of global climate change are reportedly people's destructive activities on nature [1]. Emissions of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), chlorofluorocarbon (CFC), ozone (O_3) released because of human activities are increasing excessively [2]. As a result of the increasing use of fossil fuels, the destruction of forests and misapplication in some sectors, some changes in the atmosphere have started to negatively affect our world and human life as a whole [3,4]. These impacts cause short-term and long-term effects not only on the environment, but also on the economy. Therefore, it is necessary to pay attention to how societies will be affected [5]. Many sectors that are critically important for societies to continue their economic activities are directly or indirectly affected by global warming [6]. The most important reason for global warming can be expressed as the greenhouse gases emitted from the industrial sector, whose importance is constantly increasing due to economic requirements and today's conditions, is the use of carbon dioxide fossil fuels [7]. This situation requires energy-oriented businesses to improve their environmental performance with environmentally friendly technologies [8]. Because some sectoral applications cause increased pressure on the environment. Every year, millions of people are affected by urban air pollution and water problems due to environmental pressures.

Climate change affects biodiversity on earth. The most important factor causing biodiversity erosion is biological invasions. In recent years, the movements of living organisms have gained speed and it has become easier to move them from one place to another. Depending on the changing ecological conditions, species settle in different areas from their habitats, and they provide the formation of new conditions by changing the ecological balance in their new habitat. This situation has led to ecological problems among the species. These species, known as invasive, are creatures that migrate from their places of residence to other places for various reasons or spread by expanding their habitat and establishing habitat in new locations where they migrate. Invasive species in aquatic ecosystems can be transported from one region to another in different ways as it occurs in other ecosystems [9]. Oceans, seas, mountains, and deserts, form geographical barriers on earth. Thanks to the existence of these barriers that do not interact with each other, species emerge which is specific to each region. If one of these geographical barriers is to be broken, the species will pass through the corridors to the other side and adversely affect the biodiversity where they pass. With the opening of the Suez Canal, more than 250 species, 34 new genera and 13 new families of Red Sea origin fish and at least as many invertebrate species have passed and continuously entered the Mediterranean [9,10,11]. Due to the opening of the Suez Canal, some creatures of Atlantic origin passed to the Red Sea, while marine creatures of Indo-Pacific origin began to change their habitats by migrating to the Mediterranean. Balloon fish, whose numbers of individuals have increased rapidly in the Mediterranean in recent years, cause serious harm to human health since they contain a neurotoxin called tetrodotoxin (TTX) in their tissues, in addition to the economic damage they cause especially to fishermen [12,13].

Species transitions increase not only with the opening of the channel, but also with the realization of ocean currents along with the changes in the climate. Another way of spreading these invasive species is the usage of ships. As a result of increasing ship traffic in the seas and oceans, the eggs and larvae of many creatures can travel long distances in the ballast waters of the ships or by adhering to the surface of the ship under the waterline. Eggs and larvae entering a new environment in this way, if they have survived and adapted to the new environment, begin to spread rapidly. Similar transport systems for invasive species in freshwater ecosystems are also known. For example, *Dreissena polymorpha*, a bivalve aquatic organism, is one of the species that can be transported via fishing gears and traps by the activities of fishermen who can easily cross the geographical barriers and then the species can spread very quickly. When an invasive species comes to a new habitat, it competes with the native species in the environment and over time they begin to replace the native species. In fact, by creating new hybrid species, they pose a threat to the natural balance and biodiversity by changing the genetic structure of some species.

While the struggle for the existence of every living thing continues in nature, some creatures are more successful than others in this regard. Oceans and seas, which form a large part of the world, contain many living things which are struggling to exist, and therefore these aquatic ecosystems have a rich biodiversity. However, aquatic ecosystems are most affected ecosystems by the climate change process created by global warming [14]. The effects of global climate change cause changes in aquatic ecosystems such as oceans, seas and lakes [15]. In aquatic ecosystems, it has caused a noticeable water level decrease in lake waters, melting of glaciers, rise in sea level, changes in currents and precipitation patterns. In other words, it has begun to show its negative effects on all aquatic organisms, from plankton which are the primary producers' to mammals [16]. New communities shaped by climate warming and biological invasions are reportedly spawning a 'new ecosystem' that cannot be returned to historical bases [17]. Again, in the same article, it is reported that 60% of native species do not reach the breeding length and 12% of species diversity falls on shallow subtidal soft surfaces.

Almost all natural resources in the aquatic environment can meet many demands. Although fish constitute an important part of aquatic organisms, mollusks can also meet a significant part of this need. Especially bivalve species are one of the foods that have been loved and consumed by people who are living on the seashore since ancient times. Mussels, which are bivalve organisms, are invertebrates that are an important part of the food chain in nature. It is a quite valuable and delicious food source for humans as well as being the food source of many aquatic organisms. Nutritionally, they meet the need for high polyunsaturated fatty acids and high-quality protein. In addition, they have their place among the other important street tastes [18]. It is also known that bivalve organisms are used for decoration and accessory purposes [19,20]. Especially the use of mother-of-pearl as a raw material in the production of buttons makes these organisms indispensable.

Bivalves are filter-feeding organisms and provide ecosystem services by filtering the water at a rapid rate of 3-5 l/hour in the water column [21]. During their feeding activities, they take in phytoplankton, organic detritus, bacteria and dissolved organic materials which are suitable for filtration size as their food source. In addition, they are very effective in improving water quality, as they filter and retain the pollutants such as heavy metals and dissolved substances in the water during their feeding activities. For this reason, it is important to evaluate them as bioindicator species in the investigation of water quality and ecological parameters [22,23]. The focus of this review is how aquatic bivalve species, which have ecological and economic importance, are affected by climate change damage and how strategies should be adjusted to protect these species.

2. DESTRUCTIONS OF CLIMATE CHANGE ON BIVALVES

Bivalves are invertebrates that are an important part of the food chain in nature. The labial palps surrounding the mouth of these creatures that feed by filtering water are responsible for the selection of food particles. Digestion of food occurs by secreting enzymes with the crystal-looking gelatin rod contained in the stomach of bivalves. Indigestible particles move from the posterior region of the stomach to the lower part of the descending intestine and are expelled from the rectum [47]. During their feeding activities, they consume some zooplankton species and organic detritus as well as phytoplanktonic organisms, which are the most important food sources [48]. They also filter out contaminants such as heavy metals from the water [49]. In the aquatic ecosystem, bivalves might be affected by climate change in various ways. (Figure 1). Climate change has a chain effect on the marine ecosystem by affecting both the phytoplankton takes a part in primary production in aquatic environments and bivalves which are the food source of many other aquatic organisms. According to studies, when the bivalves are fed on toxic phytoplankton, toxins enter the digestive tract through the gills and accumulate in tissue [24, 25]. Paralytic shellfish toxin (PST), potentially known as a water-soluble neurotoxin, blocks sodium channels in nerve cells in mammals, preventing signal transmission between neurons and causing muscle paralysis. As a result of this situation, deaths occur due to respiratory failure [26]. Bivalves are the organisms affected by anthropogenic activities. Thus, there are some situations that are not suitable for human consumption and have a negative effect on human health [27]. Human poisonings and deaths due to consumption of marine mussels fed with toxic dinoflagellates have also been reported [25]. However, there are no studies on

PST poisoning caused by bivalve organisms in freshwater environments. The reason for this can be explained as the low consumption of freshwater bivalves as a food source by humans. However, the presence of toxins in the ecosystem should be determined so that the aquatic organisms, fish, and birds feeding on these organisms are not exposed to toxins [25]. It is reported that shellfish are important in the spread of foodborne diseases in developed and developing countries. It has been reported that the amount of virus in bivalve organisms can be 100-1000 times higher than the water they are in, and people can be exposed to the virus cocktail during their consumption [28]. Neurotoxic Shellfish Poisoning occurs because of the consumption of contaminated shellfish [29].

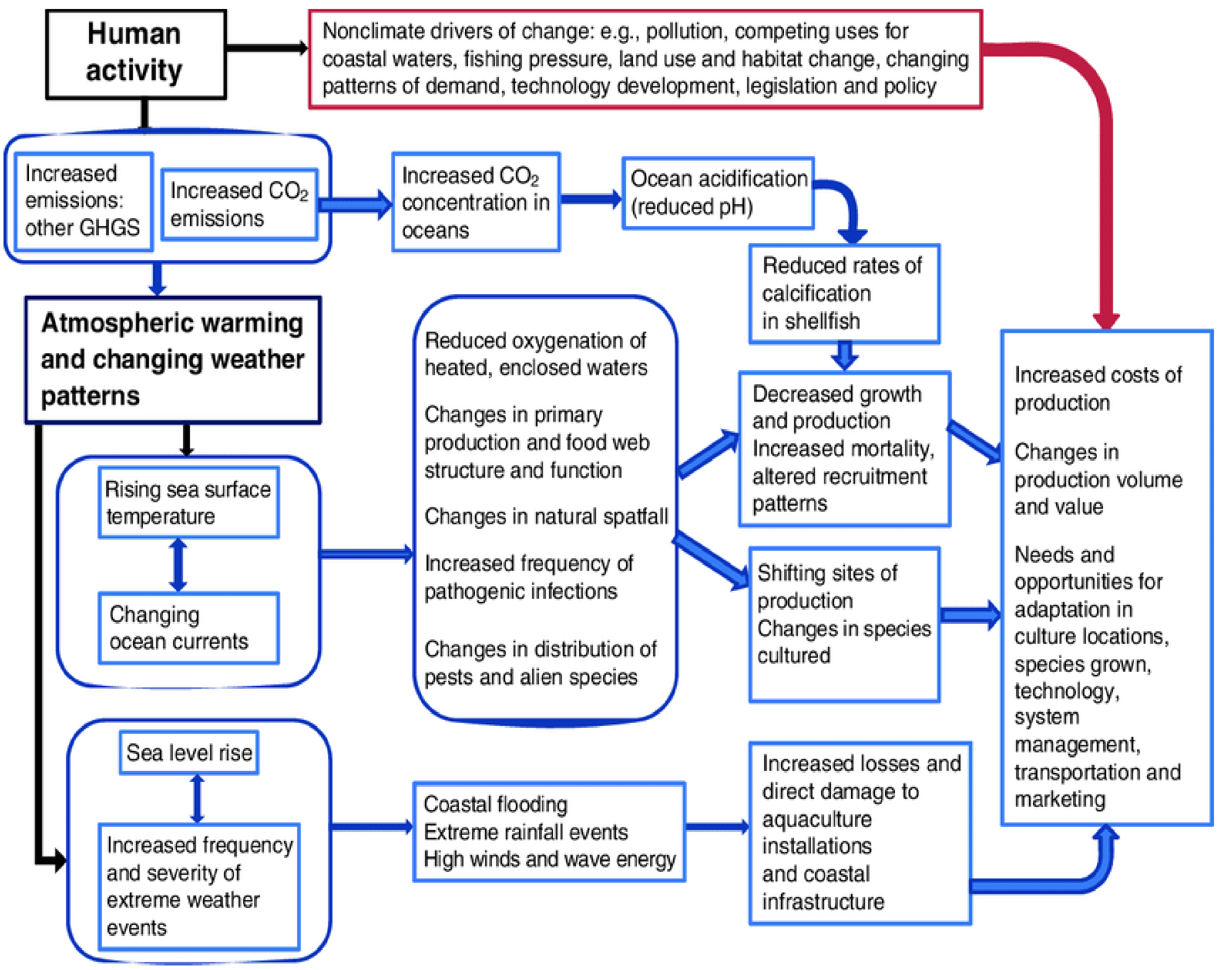

Figure 1. Various effects on bivalves of climate change [30]

One of the most important factors affecting the growth of mussels is seawater temperature. Studies have shown that optimum growth in mussels can be observed at a water temperature of 16-18 °C [31]. Seawater temperature varies according to the seasons. Seasonal changes affect many factors such as water depth, tide, water circulation rate, current speed, and direction [32]. Temperature plays an important role in bivalve physiology, gene expression, distribution, and fitness [33]. Changes in environmental temperatures can make individual stress factors synergistic [34]. At the individual level, it is reported that the physiological stress caused by a factor can reduce the resistance of the organism to other stress factors or the synergistic effect of multiple stress factors can lead to irreversible and negative consequences [35]. During periods of heavy rainfall, a large amount of freshwater enters the marine environment. Since saltwater is heavier than freshwater, the probability of presence of freshwater increases on the sea surface and in the water column. As a result of this situation, it is thought that the filtration rate, growth performance and yield of bivalve organisms will be negatively affected while they exposed to environmental stress. Changes in temperature and salinity parameters due to global warming may endanger the welfare of bivalve organisms, which have an important place in aquatic ecosystems, by increasing the stress factors. The formation, which is frequently seen in marine environments and defined as mucilage, is related to different physical, chemical and biological factors caused by phytoplankton increase due to nutrient salts [36]. Mucilage is polysaccharide structure that emerge because of the death of certain over-proliferated phytoplankton and bacterial species. These structures trap living and non-living carbon sources and cover large areas on the sea surface, water column and seafloor. It causes the death of bivalve species that live by burrowing under the seafloor, by not being able to breathe adequately. Thus, it causes both visual, ecological, and economic damages.

Freshwater bivalve species are found in a variety of permanent freshwater habitats, including streams, rivers, lakes, canals, and reservoirs. They also occasionally inhabit permanent ponds and marshes with good water circulation, usually those that are connected to a nearby lake or river system [37]. In the natural reproductive physiology of bivalve species in freshwater environments, females release their larvae in free-flowing waters during each reproductive activity in spring and summer [38]. These larvae passively detect the biochemical signs in the water, along with the water current, and reach the host creature, namely the fish, and preferably cling to the gills of the host creature and ensure its development up to the juvenile mussel stage. After metamorphosis, juvenile mussels separate from the host and survive by burying themselves in the stream floor for a while. After this period, the mussels rise above the sediment and continue their life by passing to the "filter feeding" phase. During this complicated life cycle, some of the host creatures, namely fish species, where they spend a part of their life cycles, prefer areas with dense ground vegetation to reproduce, hide or feed. Therefore, local fish populations may also decrease with the decrease of floor plants in the environment. The extinction of native ichthyofauna poses a serious threat to biodiversity reduction, as well as the introduction of diseases and parasites into habitats, along with invasive species.

Studies conducted in recent years indicate that populations of some marine mussel species caught are decreasing due to their high nutritional value, delicious meat and their shells provide raw materials for indispensable decoration materials, while some freshwater mussel species have come to the point of extinction and even some of them are extinct [39]. Warming oceans are changing the existing natural habitats of many marine species [40]. Some of the creatures that cause ecological and economic problems in aquatic ecosystems are species in the Dreissenidae family such as *Dreissena polymorpha* species. It is known that *D. polymorpha* lived in the seas until the end of 1700, then moved to freshwaters and continued to spread in Europe. It is reported that this species was detected in England in 1824 and later spread to Denmark, Sweden, Finland, Ireland, Italy and other countries of Europe [41]. Studies on this species have intensified when it infects freshwaters in Europe from its natural range and entered North America in 1988 [42]. Especially in marine transportation, aquatic plants, water currents, migratory water birds and crayfish transported in the ballast waters of ships are counted among the natural or human-induced factors that ensure the spread of these species. These species cause many economic problems when they enter a different habitat because they can reproduce very quickly and in large numbers, have a high tolerance to environmental conditions and have small freely swimming larvae. It also has serious effects on other mussel populations native to the environment. They begin to compete with native species for physical space and food. Most importantly, they survive by clinging to other mussels. This gives the zebra mussel (*D.*

polymorpha) a significant advantage in the race for space, oxygen, and food, while causing slow extinction of other species. For example, it is reported that zebra mussels will invade breeding areas of pearl mullet in Lake Van (Turkey) and cause great damage to the fisheries of the region [43]. In addition, pollutants accumulated in their bodies due to their diet are higher than other bivalve organisms and cause teratogenic formation in birds feeding on these species. Determining the places where problematic mussel species are detected is of great importance in terms of taking preventive measures against invasive mussel species.
The increase in temperature in water bodies with the effect of global warming causes changes in the physical and chemical properties of water [16]. Bivalve organisms are important in the calcium cycle in lakes and streams and mix the sediment top layer through bioturbation. Among the greenhouse gases, the solubility of carbon dioxide in seawater, which has the largest share in terms of contributing to climate change, is considerably higher than other gases in the atmosphere. The drastic increase in carbon dioxide emissions in aquatic environments causes pH reduction, increased acidification. Bivalve organisms that use calcium to form shells become more fragile and sensitive under pressure, inhibiting their ability to form shells due to the increased acidification [44].

Global climate change originated from anthropogenic activities is likely to have a major impact on marine ecosystems, affecting both biodiversity and productivity. These changes will have a major impact on humanity's interactions with the sea [45]. It is predicted that the effects of climate change will increase even more in the future. Climate change affects socio-economic sectors and ecological systems due to reasons such as rising sea level, displacement of climate zones, more frequent and effective occurrence of severe weather events, drought, epidemic diseases, agricultural pests, damage to wildlife species because of deterioration of natural balance and deterioration of human health. It is predicted that it will cause significant consequences by affecting directly or indirectly [46]. Although the consequences of global warming seem to be quite complex, according to a general view, it is estimated that many ecosystems will change with the living populations they contain, and the habitats of both animal and plant populations will change due to temperature [1].

3. CONCLUSIONS

The negative effects of global climate change and greenhouse gases are felt in different parts of the world. Awareness of this situation is becoming increasingly important. The worldwide increase in greenhouse gas emissions is associated with the growth of both human population and economy. It is predicted that the world population will continue to grow in the future. Accordingly, carbon dioxide emission rates will increase worldwide in the coming years. Therefore, it is essential to accelerate the process of moving away from fossil fuels. Finding ways to organize our society more efficiently is one of the important ways to reduce the carbon dioxide dependence of the modern world. Bivalve production is a food production method that does not have any external feed costs and has low greenhouse gas emissions in aquaculture activities. However, uncertainties about future production areas and production levels come to the fore. It is clearly seen from the literature that climate change is effective on bivalves. Consequences such as temperature increases in aquatic ecosystems due to global climate change, changes in ocean currents, sea level rise, increase in the amount of carbon dioxide, acidification, pathogenic infections, harmful and alien species will affect the growth and yield of bivalve species. The increase in mortality rates in these creatures, it will cause a decreased production volume and increased cost of the aquaculture facilities. It is beneficial to develop and support climate modeling strategies to adapt future management policies on shellfish. Sustainable production activities with a low carbon footprint should be supported and increased.

The information in this review is useful for raising awareness in ensuring the sustainability of bivalve species, which form the important link of the food chain.

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