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A REVIEW OF ADAPTATION TO CLIMATE CHANGE STRATEGIES BY PHYTOPLANKTON, ZOOPLANKTON, BENTHIC AND FISH COMMUNITIES IN A TROPICAL AND SUB-TROPICAL COASTAL ESTUARINE ECOSYSTEM

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ABSTRACT

Climate change, a global environmental phenomenon, is recognized as a major threat to survival of species and integrity of ecosystem world-wide. Adaptation strategies by species assemblages in an ecosystem are therefore aimed at reducing mortality, while they are expected to increase survival flexibilities of the species or group of species to a given climate variability scenario. These scenarios are known to impact directly and/or indirectly on the distribution, abundance, diversity, reproduction, growth and species composition. This paper reviews the adaptive strategies that will or are expected to enhance the survival of phytoplankton, zooplankton on and benthic communities/assemblages in the tropical and sub-tropical coastal waters, their community structure, life processes and roles in the ecosystem.

KEYWORDS: Climate change, phytoplankton, zooplankton, benthos, fish, adaptation, tropics, sub-tropics, coastal estuarine ecosystem.

INTRODUCTION

Climate change has been known in geological history and even during the pre-industrial age though with little or no profound effects on the environment (Hofmann and Todgham, 2010). It is now an established scientific reality, with a variety of emergent challenges for the Earth system (aquatic, terrestrial and arboreal) (IPCC, 2007). The oceans play a major role in modulating the climate system through storage and transport of heat (Barnett *et al.,* 2005), and through the uptake and sequestration of carbon dioxide (Doney *et al.,*2009; Huertas *et al.,* 2015). As the release of excess CO_2 to the atmosphere will continue, the planet and some critical ocean regions may soon be warmer than at any time in the past million years (Hansen *et al.,*2006; Belkin, 2009). It has been predicted that by the end of the 21st century, the sea surface might experience a temperature augmentation between 1.10^{o}C (Low CO_2 emission scenario) and 6.4^{0}C (high CO_2 emission scenario) (Huertas *et al.,* 2015). Warming will also be experienced by large freshwater bodies, with a rise of 1.7^{0}C in surface water temperatures due to the predicted doubling of atmospheric CO_2 concentration (Huertas *et al.,* 2015).With these ever unending scenarios in climate change (Fig. 1) and attendant effects on the components of the Earth, including the marine and coastal ecosystems what are the likely adaptation strategies that are being employed (or will be employed) by communities such as phytoplankton, zooplankton, benthos and the fish communities, to enable their continuous survival flexibilities for enhanced distribution, abundance, diversity, reproduction, growth and species composition in the aquatic ecosystem.

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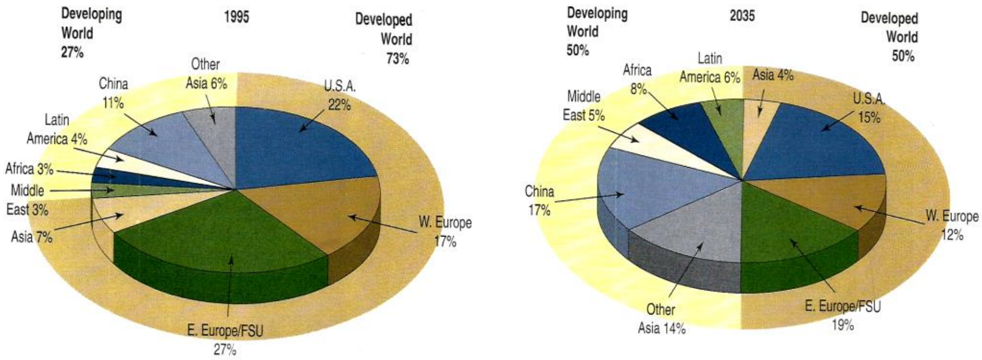

Fig. 1: Generalized structure of projected global emission of carbon dioxide up to 2035.

Source: Data from "Climate Change-State of Knowledge" October, 1997, Office of Science and Technology Policy, Washington, D.C and State of the World 2000.

In 1995, the industrialized nations of the world contributed nearly three-quarters of the global emissions of carbon dioxide, with the United States, being the largest single emitter. By 2035, developing nations will catch up and contribute half of the global emissions, with China becoming the largest single emitting country. Rapid population growth, industrialization and increasing consumption per person in the developing world will contribute to this shift.

This paper is therefore aimed at reviewing the basic adaptation strategies likely to enhance these communities to carry out their fundamental roles for a balanced ecosystem.

Theoretical perspective

Climate change is a significant and lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years. It may be changes in average weather conditions, or in the distribution of weather around the average conditions and its effects on the survival, growth, reproduction, distribution and adaptation of individuals within a species (Patrick, 2016). The basic theoretical belief on the causes of climate change has been placed into four categories namely astronomical causes, volcanic eruptions, variations in solar output and human activities (IPCC, 2001, 2007). Among these, human activity has been recognized as the most prominent factor responsible for the current climate change. This normally occurs through the emission of green house gases (mainly carbon (iv) oxide, methane, halocarbon and nitrous oxide (IPCC, 2001, 2007).

Adaptation strategies

Adaptation is here defined as the ability of an organism to adjust in natural or human system in response to actual or expected climate change or their effects (Akinrotimi & Edun, 2013).

In this direction, the following adaptation strategies have been reported for each of the communities considered in this context.

Phytoplankton

Despite their microscopic size, phytoplankton support about half of the global primary production, drive essential biogeochemical cycles and represent the basis of the aquatic food web (Huertas *et al.,* 2015). At present, it is known that phytoplankton are important targets and, consequently, harbingers of climate change in aquatic systems. Therefore, considering the polyphyletic complexity of the phytoplankton community, different responses to increased temperature, including photoperiod are the main interplaying factors influencing them to adapt to the climate change effects (Huertas *et al.,* 2015; Muren *et al.,* 2005).

These basically may include one or all of the following:

i. Species dispersing to more hospitable habitats, (Huertas *et al.,* 2015).

ii. Development of phenotypic and physiological plasticity to allow tolerance in the new conditions (Magnuson *etal.,*1997).

iii. Species ability to adapt to the new conditions through genetic change will be via the process of evolution (Hofmann and Todgham, 2010; Sniegowski and Lenski, 1995).

The possible explanations supporting species adaptation to new conditions through genetic change based on the process of evolution are that, beneficial mutation of the genes allows survival at increasing temperatures. This adaptive feature however cuts across the three assemblages (phytoplankton, zooplankton and benthos) (Huertas *et al.,* 2015; Sniegowski and Lenski, 1995)Drifting life forms, whose spatial distribution is primarily determined by the motion of the water column (such as those integrating the plankton community, particularly some larval forms of benthos (which are zooplankton at that stage (i.e. larval stage) and bottom-dwelling (i.e. benthos at adult stages), rely on the last two mechanisms to cope with the increased temperatures, considering the environmental selection forcing (rising temperature and photoperiod) (Huertas *et al.,* 2015; Muren *et al.,*2005; Marva *et al.,* 2010).

There will be generally, a swift towards a dominance of small-celled phytoplankton communities (that would have its primary origin in a temperature – driven environmental process, such as nutrient supply or potential grazing, owing to the impact of warming on zooplankton, rather than in a direct thermal effect on the phytoplankton metabolism (Huertas *et al.,* 2015; Marva *et al.,* 2010).

Zooplankton community

The zooplankton may exhibit the following adaptive measures:

i. Body size reduction to enable them adapt to temperature and photoperiod differentials.

ii. Pole-ward shift and distribution of species, especially thermal specialist species.

iii. Production of small-sized, compact and more eggs.

iv. Altered phenology (responding to the different doses of the temperature and photoperiod) based on the biological clock mechanism to enable reproductive process.

The copepods, in the zooplankton community, have been known to exhibit these basic adaptive strategies (Dam and Baumann, 2017).

Benthic Community

Benthic communities and constituent species are sessile or have low mobility. However, they are capable of responding to climate change by way of developing or being able to develop adaptation strategies, which enable them maintain their population and ecological roles (Dam and Baumann, 2017).

With their sessility, some basic adaptive strategies have been reported. In considering the adaptation of the benthos to climate change, the polychaetes belonging to the family Nereidae are reviewed. Nereidae are semelparous (Lawrence and Soame, 2004). This means that gametes are developed and released once in a lifetime, after which the adult dies. Typical Nereidae species are known, and include *Nereis virens*, *N. diversicolor*, *Harmothoe imbricata*, *Nephtyshom bergii* and *Eulalia viridis*.

Adaptation strategies

For these animals, the synchronous timing of reproduction which is very crucial and tightly controlled, not only within the individuals, but also across the population has been developed as a biological mechanism (Garwood and Olive 1982; Baduini *et al.,*2001; Lawrence and Soame, 2004). There is also a strategy to release eggs and developed larvae during periods of abundant food supply (Olive *et al.,* 1990).

An explanation to the first strategy is based on the fact that temperature and photoperiod both influence the gametogenic process in the nereids (Last, 1999; Lawrence and Soame, 2004). These authors are of the view that low temperatures (7 – 12^{0}C) will encourage oocytes growth in nereids, while high temperatures will inhibit growth of the oocytes. Short photoperiod (Light – Dark (L:D) 8: 16h) will also promote oocyte growth, while long days (L:D (16 – 8h) will inhibit it (Last, 1999; Lawrence and Soam, 2004; Baduini *et al.,* 2001).

Therefore, bearing in mind that these benthos die after release of gametes (ie development and release of gametes occurs once in a lifetime in nereids), for these groups of benthos in particular to maintain their population and ecological functions, the synchronization of the reproductive cycle has been developed as an adaptive strategy (Lawrence and Soame, 2004). The third adaptation strategy has been that of producing few larger eggs and greater number of smaller eggs as temperature rises, with attendant longer photoperiods. Large egg sizes of nereids were reported to still remain viable under increased temperatures (Baduini *et al.,* 2001) in South-Eastern Bering Sea during the Summer of 1997, while Clark (1988) reported that small-sized nereid eggs under the influence of rising temperature and longer photoperiod were still alive and viable in Humber estuary, Northeast England. This suggested the importance of benthos to be able to adapt to climate change by developing few larger eggs and greater number of small-sized eggs through a synchronized reproductive cycle, based on temperature and photoperiod effects. The eggs of Flounder fish have also been carefully studied by Dam and Baumann (2017) in relation to their adaptive strategies in Rhode Island to exhibit the strategy of reproducing few larger eggs and large number of small-sized eggs.

Fish community

As climate change continues to exacerbate existing ecological conditions in the aquatic ecosystem, it poses significant and long-term risks to fisheries community in relation to survival, growth, distribution, reproduction and the subsequent recruitment into the standing stock of the fish population (Ayub, 2010; Garcia and Rosenberg, 2010; Hlohowskyjl *et al.,* 1996).

Dwindled fish population due to the impact of climate change has been variously reported in the sub-Saharan waters (Mohammed and Uraguchi, 2013; Nye, 2010; Feidi, 2019; Olaoye *et al.,* 2010) and other parts of the world (Harley *et al*., 2006, Scavia *et al.,* 2002; Hughes *et al.,* 2003; Hamilton *et al.,* 2000).

The effects of climate change have been and are being resisted by fish communities in the different aquatic ecosystems by the development of various adaptive strategies among which have been reported to include:

i. Delayed reproduction to fit into a particular environment's cue, depending however on the life history of the species or family and which cue is considered by the fish most crucial for its physiological functioning (Lawrence and Soame, 2004; Ayub, 2010; Patrick, 2016; Olaoye *et al.,* 2010).

ii. Becoming larger than expected at maturity to enhance higher fecundities, particularly in non-migrant species. This adaptive strategy has long been reported in three spine sticklebacks *(Gasterosteus aculeatus*) in the Californian (Synder and Dingle, 1989).

iii. Gene tinkering (turning on of genes). Gene tinkering has been reported as a specialized adaptive strategy in brackish and marine water fishes in which a fish "turns on" its genes to adapt to climate change at relatively short periods of time in the evolutionary context. Myelnikov (2019) reports that this has been particularly observed in skate fishes off Canadian coast for them to survive warmer water temperatures. Gene tinkering has also been reported in winter skates, off the Labrador Peninsula in which they were observed to change their body structure to better suit the areas warmer waters, but that they were not evolving, instead were simply switching which genes they choose to "turn on" to enable adaptation to a particular physiological function(s).

According to Myelnikov (2019), in some cases, the winter skates do this not by changing their DNA sequence, but by simply changing how they express their genes. "This form of adaptive strategy is elaborately caused by epigenetic changes and is different from the normal process of evolution", reported Myelnikov (2019). Again, in the Southern Gulf of St. Lawrence, the winter skates found along the North American coast were observed to be much smaller in size than their counterparts in the rest of the Atlantic Ocean. Therefore, for fishes to survive warmer waters, they become smaller in size (Myelnikov2019).

The generality of gene tinkering as an adaptive strategy can be explained more by the fact that changes in gene expression do not rely on the slow changes in the DNA, it only describes the process of switching on or off of parts of the DNA that have specific functions.

Schultz (2007) and Myelnikov (2019) maintain that genes can be turned up or down so that their functions become stronger or weaker given the prevailing climatic condition.

In this basic genetical functioning, unlike evolution, the process of gene tinkering is extremely quick and can sometimes take place in just a matter of days (Myelnikov, 2019)). In tropical and sub-tropical estuarine waters, certain species have become better equipped to deal with rapid changes in climate than others particularly those that have a longer life span and lower reproductive rates. These have been observed in skates in the Southern Gulf of St. Lawrence, off the Labrador Peninsula by Myelnikov (2019).

iv. Local adaption: In local adaptive strategies, fish species in a particular environment have become fit (i.e have higher fitness to survive in their environment than individuals from elsewhere and is the first step an individual species become ecologically speciated, depending however on the life history of the species at the cellular level. In local adaption, instead of the species migrating to an environment with an unknown or an unfamiliar ecological setting, it cellularly adapts to the changes in its local environment. This has been observed and reported in the common Killifish *(Fundulus heteroclitus*), inhabiting the marshes and estuaries along the Atlantic Coast of North America from New Found Land to Florida by Schultz (2007).

DISCUSSION

Natural climatic fluctuations, particularly those at medium (decadal) scale, have always affected arboreal, terrestrial and aquatic organisms (Garcia and Rosenberg, 2010, Barange and Perry, 2009, IPCC, 2001, 2007, Bindoff *et al.,* 2007). According to Christensen et *al.* (2007), warming in tropical and sub-tropical coastal waters is very likely going to be larger than the global annual mean warming throughout the region and in all seasons. The tropical regions according to Mohammed and Uraguchi (2013), will become more drier than the wetter tropics, with a consequent decline in rainfall/rising water temperature known to threaten biodiversity (Abowei, 2010), and according to IPCC (2001, 2007; Urama and Ozor, 2010; Schallenberg and Burns, 2003), if water rises above the maximum tolerable threshold of a species, then its existence including other biological activities of the species are threatened. Urama and Ozor (2010) provide an example from the Labiden highlands in Cameroon where women have started hunting tadpoles and frogs because there are no fish in most of the Bangwa Rivers. According to Urama and Ozor (2010), even the number of tadpoles and frogs have significantly declined (partly) due to the warming rivers that have caused increased number of predator fish in an area they have never inhabited before.

Climate change can cause an increase or decrease in water salinity and this may happen in multiple ways (Mohammed and Uraguchi, 2013), while tropical and subtropical coastal water including the oceans are increasingly becoming saltier, those closer to the poles are becoming fresher (Schallenberg and Burns, 2003; Mohammed and Uraguchi, 2013).

This highlights that tropical and subtropical and estuarine systems and oceans are very likely to suffer more from the potential impacts of increasing water salinity for example, relative to waters in higher latitudes (Schallenberg and Burns, 2003). Changes in water salinity (one of the many outcomes of global warming) have different effects depending on the tolerance level of the organisms and the nature of their ecosystem generally – whether freshwater, estuarine or marine. The salinity of some freshwater ecosystems have been predicted to increase as a results of anthropogenic climate change (IPCC, 2001). Such physical changes are known to have negative impact on the population of plankton, benthos and other aquatic species (Schallenberg *et al.,*2003).

One of the most important variables that determines the survival of organisms in estuarine ecosystems is salinity (Marshall and Elliot, 1998; Abowei, 2010). Salinity has a direct impact on the organism and can also indirectly destroy the habitats of the organisms, including their breeding and nursery grounds (Marshall and Elliot, 1998; Abowei, 2010; Mohammed and Uraguchi, 2013). In a previous report, Schallenberg and Burns (2003) noted that zooplankton communities of low-lying, coastal, tidal lake and wetlands are already adversely affected by small increases in salinity levels. It was concluded that such changes in zooplankton abundance may further disturb the ecological functioning of the valuable, but vulnerable ecosystems.

According to Blaber (2000), all estuarine fish are euryhaline, this may or may not be true for all species of benthos, zooplankton and phytoplankton, as the ability for an organism to cope with salinity fluctuations varies from species to species, hence, changes in salinity is likely to influence the distribution, survival and adaptation of the benthos, zooplankton, phytoplankton and fish in the tropical and sub-tropical estuarine ecosystems. Mohammed and Uraguch (2013),are of the view that even though salinity changes may not have a direct negative effect on estuarine species (fishes, plankton and benthos) per se, it is likely to have a negative impact on their habitat. This is informed by the report of IPCC (2007) that water salinity has contributed to the destruction of 60 percent of mangrove areas in Senegal. Parkins (2000) noted that each acre of mangrove forest destroyed for shrimp farming leads to an estimated 300kg loss in marine harvest in Senegal, and that change in water salinity had tremendous negative impact on fishery in the Senegalese region, threatening the livelihoods of many impoverished coastal communities.

Generally, climate change is already affecting the trends of some very important biological processes resulting in changes in primary production (Taucher and Oschlies, 2011; Mohammed and Uraguchi, 2013). Inorder to adapt to the negative impacts of climate change, biological communities including the benthos, zooplankton and phytoplankton have developed different adaptive strategies to enable them survive, grow, reproduce and become distributed in their natural habitat therefore enhancing their continuous ecological functions in the ecosystem.

CONCLUSION

The adaptive strategies exhibited by an individual biotic community considered in this review, depending on their respective life history, could provide real insight into how future climate change may affect aquatic biodiversity, particularly at the estuarine and marine levels. Just as there are still a handful of unanswered questions on the impacts of climate change on the different groups or communities of organisms, there is strong need for further researches to be conducted to plug gaps in the different adaptive strategies that may be (or are likely to be) exhibited by these communities.

When climate change is slow and gradual species may have time to adapt to more suitable ecological conditions and locations and "invent" other biological and physiological processes that will (or likely to) promote their ecological roles in the ecosystem and their chosen niche. But when climate change is relatively abrupt, many organisms are (or will be) unable to respond before conditions exceed their tolerance limits. Whole communities may be destroyed, and if the phenomenon is widespread, many species may become extinct as issues of climate change are unending.

DISCLOSURE STATEMENT

We declare that this review has no potential conflict of interest.

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