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Paradigm of Climate Change and its Influence on Zooplankton

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Zooplankton are the precious elements of aquatic ecosphere playing a significant role in some ecological phenomena viz., biomonitoring, ecological indication, link between primary producers and higher trophic levels, aquaculture, and maintenance of balance in aquatic food webs. The climate, being a dynamic abiotic entity, changed many times during the history of earth particularly before and after the industrial revolution. The unending materialistic benefits of human beings have been increasing the concentration of greenhouse gases such as carbon dioxide, methane, nitrous oxide, and fluorinated gases since the last few decades that is enough to raise the global temperature. It is a fact that both biotic and abiotic factors affect the dynamics of aquatic biota due to which the aquatic ecosystems and the organisms inhabiting them such as zooplankton are becoming the worst targets of the climate change phenomenon. Some of the significant consequences of climate change posing threats for the zooplankton community include increased temperature, acidification, nutrient enrichment, and increasing ultraviolet (UV) environment of the aquatic ecosystem that significantly affect their survival, behaviour, nutritional procurement, reproduction, and their overall population dynamics. Due to the profound effects of climate change on the zooplankton community, the entire aquatic food web gets crushed away leading to more severe concerns about the higher trophic levels and overall dynamics of the aquatic biota. Thus, unending loss in the dynamics of the aquatic ecosystem could prevail and will go on expanding if the causal factors of climate change continue to operate beyond their limits unless a strong scientific policy and framework in contrary to climate change are reinforced with the key focus on aquatic biota especially zooplankton.

Keywords: Aquaculture, Biomonitoring, Climate change, Food web, Greenhouse gases, Zooplankton.

Weather across the entire planet over time has always varied and is still varying because of the interactions between the components in the climate system (atmosphere, oceans, ice sheets, etc.). Climate change is a long-term swing in the weather statistics such as temperature, precipitation, or wind[1] and is considered the major significant environmental issue for the current generation[2]. The amount of energy in the entire climatic system is changing due to change in energy received from the sun and the amount of greenhouse gases in the atmosphere, which in turn affect every module in the system leading to Climate change. The results of climate change are havoc ranging from melting of glaciers resulting in extreme floods up to the change in species distribution[3,4]. Climate is changing due

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to natural attributes (variations in the sun's output and earth's orbit around the sun, volcanic eruptions, and internal fluctuations in the climate system such as El Niño and La Niña) as well as through anthropogenic influences (e.g., industrialization and emission of the huge amount of greenhouse gases). The evidence from the "fingerprint" studies of carbon dioxide that compares the average CO_2 emissions from volcanoes and human activities revealed that humans are emitting an estimated 36 billion tons of CO_2 each year, 80-85% of which are from fossil fuels but volcano emissions are only about 200 million tons per year[5], therefore a clear prediction is that natural causes alone are inadequate to explain the recent observed changes in the climate. Climate warming is clear and researchers around the globe are 90% certain that mostly it is caused by the rise in greenhouse gas concentration due to anthropogenic activities viz., fossil fuel burning and deforestation[6,7,8]. Therefore, additional CO_2 get released into the atmosphere much more rapidly than in the natural carbon cycle. With the result, there is disturbance in temperature distribution, clouds, air-currents, rainfall, evapo-transpiration, melting of polar ice-caps and rising of sea level that could adversely affect natural ecosystems like fresh water resources, agriculture and food supply, biodiversity and human health[9]. The global climate is constantly changing and the last decade of the 20th century up to the beginning of the 21st century observed the highest temperature record and hottest climate globally[1]. The studies have shown that the current climate disturbance is contributing towards the surface temperature of earth[10], rise in sea temperature[11,12], change in the flux of particulate organic matter (POC) to the sea[13,14], the decline in pH[15], and deoxygenation[16,17]. Over and out, all the above changes are bellwethers for what climate scientists forecast, will make dramatic impacts on the biosphere in decades to come[18].

Zooplankton comprise of minute aquatic organisms ranging in size from a few microns to a few millimetres or more, are either non-motile or weak swimmers drifting in oceans, seas, or freshwater bodies, and are significantly associated with changes in phytoplankton community[19]. Zooplankton play a vital role in the aquatic food web by feeding on the phytoplankton and other members of zooplankton[20] and hence they act as a major agent in the energy transfer between phytoplankton and fish[21]. The diversity and abundance of the zooplankton community strongly affect the biotic components of the aquatic ecosystem[22]. The freshwater zooplankton group includes Rotifera, Cladocera, Copepoda, and Ostracoda. Rotifers comprise microscopic, soft-bodied invertebrates, which serve as a major source of food for fishes[21] and also act as bioindicators[23]. Cladocerans are known to be the most significant herbivore in the lake plankton community[24] and are dominated by filter-feeding species. Copepods act as a vital source of food for many larger invertebrates and vertebrates including zooplanktivorous fishes and prawns[24] and thus encompass a major portion of the consumer biomass in aquatic habitats. Ostracods are of great interest as they are found in heavily polluted areas[25] therefore, can be used as indicator species of climate and ecosystem changes[26].

Since the communities in any ecosystem are structured by a combination of both intrinsic (competition, parasitism, predation, and mutualism) and extrinsic (interactions involving effects of the environment on them) interactions[27,28]. Both types of interactions affect the dynamic pattern of individual taxa because climate change could modify communities in unpredicted ways viz. when the effect of climate on one individual is transmitted to other species via biotic interactions like food webs and other aquatic biological phenomena like eutrophication[29]. Climatic change in combination with other natural factors possibly makes the ecosystems less flexible and therefore suddenly restructure the communities and cause drastic modifications to ecosystem structure and function[30]. Different abiotic factors (viz., availability of light, temperature, salinity, nutrients, and pH) and some biotic factors (viz., parasites, predators) are controlling elements of plankton community structure[31,32]. Allied to this, some meteorological attributes viz., direction and intensity of wind and the Atlantic Multidecadal Oscillation (AMO), the North Atlantic Oscillation (NAO), and El Niño possess significant effect to alter hydrography and ocean stratiûcation that contributes to long-term variation in the diversity and abundance of plankton[33]. Zooplankton quickly react to variation in the physico-chemical and biological attributes of their environment (bioindicators of climate change), because of their poikilothermic nature, sensitiveness, short life cycle, and free-floating behaviour for their entire life, thus making them immediate victims of the climate change[34,35]. Therefore, the overall growth and abundance of plankton vary with respect to season, climate, and water properties, which will reveal the diversity of these important organisms within their ecosystem[36,37,38,10]. Hence the climate is significantly accepted as a key factor for the determination of long-term fluctuations in plankton communities, both in marine as well as limnetic ecosystems. Studies around the world predicted the three most important facets of climate change affecting the zooplankton viz., 'temperature'[39], 'nutrient enrichment'[40] and 'acidification'[41] (Figure-1 and Table-1). Thus, keeping in view of the significant importance of zooplankton and one of the worst victims of changing climate patterns, the aim of the present compiled review was to highlight the significant effects of changing climatic patterns on zooplankton based on the field as well as laboratory experiments, that could pave way for the conservation and management of such valuable creatures of the aquatic ecosphere.

Mechanism of Climate Change

Due to the importance of climate change globally, several high-level meetings have been held since 1967 after Nobel laurate Swedish scientist Svante Arrhenius in 1896, first calculated the warming power of excess carbon dioxide (CO_2)[8] and projected out that if human activities increase CO_2 levels in the atmosphere, a warming trend would result. From 1800 to 2012, the atmospheric CO_2 increased by about 40%, projected as a result of direct measurements of CO_2 in the atmosphere and air trapped in ice[42]. According to Intergovernmental Panel on Climate Change (IPCC), anthropogenic sources of greenhouse gases are responsible for the rise in global surface temperature from 1951 to 2010[43]. The elementary understanding of climate change is based on the heat-trapping property of greenhouse gases. The composition of greenhouse gases (carbon dioxide, methane, nitrous oxide, and water vapour) comprises a little portion of the earth's atmosphere and form a blanket type of structure in the atmosphere that keeps the heat in the lower atmosphere, thus are valuable for keeping enough optimal warmth of the planet for the sustenance of life. On one side, there occurs a progressive increase in the CO_2 concentration and influx of greenhouse gases viz., methane, nitrous oxide that trigger global climate change and thus contributing towards change in the ecological regime of water resources, ice melting as well as altered precipitation[44]. On the other side in nature, a continual exchange of CO_2 occurs between the atmosphere, animals, and plants via photosynthesis, respiration, and decomposition. Allied to this, CO_2 exchange also occurs between the atmosphere and oceans. Soon after the energy from solar radiations hit the earth's surface, a portion of it is reflected but most of it gets absorbed by oceans and land but is later on radiated back in the form of heat. The absence of huge concentration of greenhouse gases makes it possible for heat to escape to space due to which average temperature of the surface of the planet remains below freezing but some portion of this heat is redirected downwards that keep on heat near the surface of the earth. The upsurge in the normal concentration of greenhouse gases in the atmosphere intensifies the natural greenhouse effect of the earth (forming a thick blanket) potentially raise the surface temperatures. Temperature rise, however, is not only the sole phenomenon associated with climate change but deviation in precipitation process, wind, and recurrent floods, droughts, etc. all these signify major attributes of climate change, thus disturbing the abiotic and biotic template[45]. Thus, global climate change possesses numerous effects on aquatic ecosystems and its bad results are predicted to expand largely in the near future[46].

Effect of Climate Change Induced Increasing Temperature on Zooplankton

As different species show distinctive responses with respect to change in environmental temperature, therefore, due to climate change, unexpected costs result[47,48,49]. Large zooplankton (crustaceans) are known to be more sensitive to elevated temperatures than smaller taxa[45]. It has been shown that the top of plankton food webs are prone to climate warming and that top-down effects possess a stronger effect in shaping cascading interactions among the plankton community[50]. Generally, higher trophic levels show more susceptibility towards elevated temperature, because the consumer metabolic demands possess more sensitivity to warming than primary producers[51]. This leads to higher grazing rates and ultimately reduced consumer fitness when intake of energy by consumers cannot stay in touch with their metabolic demands[52]. In general, with increasing or decreasing temperatures, different rate processes in poikilotherms get altered, and thus, due to annual temperature fluctuation of a lake, the zooplankton production, their physiological life span, and generation time are greatly affected. For example, water temperature exhibited considerable upsurge in cladoceran concentrations (over 3-fold increase since 1946) and somehow declines in copepods[53,54]. Generally the effect of temperature on zooplankton may be direct (viz., effects on growth, development, reproduction, behaviour, and population dynamics) as well as indirect (mediated by changes in the algal community and algal food quality), all of which can affect the outcome of zooplankton interspecific interaction or competition[55].

Effect on Behaviour and Survival

Zooplankton are known to quickly adapt their behaviour to changes in their environment and as per various studies, behaviour being the ûrst response against deviation in the environment, marks eûect on individual fitness as well as species interactions, thus inûuencing the whole ecology of the ecosystem[56]. Generally filtering, ingestion, and respiration rates in zooplankton increase until the temperature where the maximum filtration rate is achieved[57]. Since temperatures near or slightly above 20 °C are often reported as optimum for Cladoceran filteration[58]. Above the thermal optima, filtering rates decline as the temperature approaches lethality. Elevated temperature alters water viscosity and dissolved oxygen, therefore, indirectly affect zooplankton feeding which is differentially affected by water viscosity, and the water viscosity favours different species at different temperatures[59]. The less dissolved oxygen at higher temperatures can also diminish feeding rates, existence, and growth of the zoolplankton[60]. Some zooplankton species survive at temperatures as high as 30 °C to 32 °C[55], but survival and longevity generally increase at low temperatures. Above 25 °C some species of zooplankton can't survive e.g., *Chaoborus flavicans*, when reared from hatching to pupation at 30 °C, shows 100% mortality in the fourth instar or pupal stage[61]. Other poor survivors among zooplankton against elevated water temperature include *Mysis relicta and Senecella calanoides*[62]. It was shown that as the temperature increases, there is a reduction in the size of marine phytoplankton[63], but phytoplankton size being an important factor in determining trophic connections[64], it is likely that warming lessens the strength of interaction between zooplankton and phytoplankton by choosing for small cell sizes that are grazed by zooplankton less efficiently. Another similar kind of study revealed that a significant reduction in the grazing rates of tropical copepods was observed when there was a 6 °C rise in temperature from a coastal power plant[65] while in other the alteration in migration pattern of marine zooplankton migration, thus creating an unsuitable area to live that affects the aquatic life in the oceans[66].

Effect on Growth, Development, and Reproduction

Since metabolic rate influences the growth of organisms and temperature is a primary variable affecting biological activities by influencing metabolic rates[67]. It is also pertinent to mention that warmer temperature acts as an induction to reduce the size of planktonic species[68]. Thus, there occurs an inverse relationship between warming and species growth[69] and also rise in metabolic rate, reduce the species growth rate[70]. Temperature and the rate of development in many aquatic invertebrates also possess inverse linear relation[71]. Since temperature and food availability are among the most vital features that control the abundance of freshwater zooplankton. Temperature generally controls the growth and hatching rates whereas the food availability affects the fertility of females and the survival of their offspring[72]. Growth rates of individuals and size at maturity are strongly affected by elevated temperature in zooplankton like rotifer[73], Chaoborus[74], Copepods[75,] and Cladocera[76]. In general, growth rates increase with temperature until a thermal optimum is exceeded, and then growth declines. Antagonistic to this, there is a decline in body size at maturity usually with rearing temperature even when food and other resources are not limiting[77]. *Daphnia magna* is found to possess toleration towards high temperature (25 °C)[78] but the hypothermic stress (decline in body mass, decrease in body size, and loss of body water) was observed after acclimation at 27 - 29 °C for one month that indicated similar kind of responses in field population due to climate change[79]. Also, the reduction in body size of Cladocera was observed in lakes at a latitude from

6æ% to 74æ% with the rise in temperature[80]. Some researchers found during their experimental studies that, survival and reproduction in harpacticoid copepods declined when exposed to thermal stress[81,82]. Some Splashpool harpacticoids can withstand a wide range in temperature fluctuations during the day[83], but a rise of temperature continued over time resulted in lethal and sublethal effects[82]. There is an obvious adverse effect of a 4 ºC rise of temperature on the reproductive success in tropical copepods and an increase of 2"4 ºC temperature leads to a decline in survival and reproduction[84,85]. Similarly moderate to intensive heat waves result in thermal stress that resulted in a decline in survival and egg production of a copepod (*Centropages velificatus*)[86].

Effect of Climate Change Induced Nutrient Enrichment on Zooplankton

The precipitation swings, rise in air temperature, and increased concentration of greenhouse gases (particularly CO_2) are the major consequences of climatic variations to freshwater ecosystems[87]. In addition to high runoff, the elevated water temperatures and more prolonged summer stratification increases the soil erosion and significantly cause extensive climate-related eutrophication[88] because increased runoff and soil erosion causes enrichment of nutrient load from nitrogen to lakes and rivers. There occurs an effect on lakes due to climate changeinduced storms by cooling, mixing, and perhaps by destratification of the water column[89]. Allied to this, the water quality around the world is in constant danger due to changing climate and anthropogenic input of nutrients[90]. Due to the climate change induced rise of net precipitation in winter and increase in extreme rainfall events, phosphorous loading of lakes takes place[91]. The change in the concentration and ratio of limiting nutrients i.e. Nitrogen and phosphorus in aquatic systems affect the system productivity and composition of phytoplankton community[92,93]. The rise in Phosphorous inputs and elevated temperatures in freshwater ecosystems could be the causal agents of noxious cyanobacteria blooms[94]. In addition to many physicochemical parameters (low CO_2 supply and light limitation), the changing nutrient and temperature conditions are the potential drivers for the development of blooms of cyanobacteria[95,96]. Thus, increased nutrients and higher water temperature leads to overgrowth of blue-green algae, resulting in harmful toxic blooms in lakes and estuaries that potentially decrease water transparency, causing deoxygenation (hypoxia) and increased occurrence of fish kills. When the concentration of oxygen falls below species-speciûc thresholds, reproduction and survival of zooplankton are directly affected[97,98,99]. In one of the experiment, it has been found that due to hypoxia, the dominance of gelatinous zooplankton increase relative to crustacean zooplankton, cyclopoid copepod dominance increase relative to calanoids and total abundances and biomass of zooplankton decrease[100]. Some other studies also revealed the upsurge in gelatinous zooplankton inhabiting eutrophic and otherwise stressed coastal waters[101,102]. Hypoxia possesses a negative effect on total biomass and abundance of zooplankton[103,104], but some studies are contrary[105,106,107], e.g. polychaete larvae show inverse relation with oxygen concentration[107,108]. The hypoxia can also lead to shifts in pelagic community structure temporally, thus favouring some taxa with greater tolerance towards hypoxic conditions[109]. In addition to this, the nutrient enrichment phenomenon due to climate disturbances reduces the ability of zooplankton to control algal blooms as it becomes very difficult and harder for them to feed and digest the blue-green algae which are very dominant in eutrophic lakes[110]. Since *Daphnia* is most sensitive to warming water and susceptible of being eaten by fish and on the other side, the lake with warmer waters has higher densities of fish that eat zooplankton[110]. So, climate change and eutrophication reinforce the blooms to become more and more. Amongst other observable changes, increases of dissolved organic matter (DOM) resulted from the climate change[111,112], has resulted in "browning" of waters in the recent past[113,114,115]. The rising of DOM leads to light attenuation, thus reducing photosynthetically active radiation and negatively impact primary producers of aquatic ecosystem[116] that in turn could affect zooplankton species.

Effect of Climate Change Induced Eutrophic Blooms on Zooplankton

Climate change leads to an altered stratification pattern of the aquatic ecosystems that significantly impact the nutrient regime[117] and availability[118]. It has been found that stronger stratiûcation may lead to community shifts, thus taxa with greater ability to regulate buoyancy (such as cyanobacteria) are favoured[119]. Cyanobacteria are considered as insufficient nutrition for zooplankton due to less nutritional values[120], inappropriate size and shape[121,] and their significant toxicity[122,123]. Thus, some zooplankton species show decreasing fitness because of higher respiration rate or egg abortion due to the high abundance of large colonial or ûlamentous cyanobacteria[124]. Also, the significant effect of cyanobacteria on zooplankton is the mechanical interference of food gathering by their filaments[125,126]. The large algal particles could potentially reduce the filtering efficacy of zooplankton grazers and the same was analyzed experimentally wherein poor growth and reproduction were observed in zooplankton which were fed on the diets of cyanobacteria in the laboratory that could be attributed mainly due to high energetic budget for low ingestibility[126] and insufficient nutritional makeup[127]. Other laboratory studies predicted the toxicity of cyanobacteria such as *Anabaena flosaquae*[128,129] and *Microcystis*[130,131] could also be responsible for damaging effects to *Daphnia* and such kind of toxic effects are expected to occur in nature also. Some field-based studies suggested that large zooplankton grazers such as *Daphnia pulex* selectively ingest competitive phytoplankton and thus help in the selective growth of colonial cyanobacteria, that gets support from experimental evidence of Haney (1987)[132] wherein, in eutrophic lakes dominated by cyanobacteria, zooplankton graze on small particles which are 100% per day but as compared to smaller phytoplankton, the colonial cyanobacteria were preferably not grazed rapidly. Furthermore, zooplankton grazers face deleterious effects from cyanobacteria, and some filamentous cyanobacteria e.g., *Anabaena* and *Oscillatoria* can hinder the filtering behaviour of Cladocerans thus retarding their growth and reproduction and it was also confirmed in the laboratory studies that the zooplankton face clear detrimental effects from nutritional deficiencies and toxins of cyanobacteria[132]. As per the experiments across the shallow sites in lake Champlain USA[133], the negative relationship occurred between metrics of cyanobacterial density and zooplankton diversity whereas, a positive relationship occurred between phytoplankton and zooplankton diversity because, with an increase in cyanobacteria density at shallow

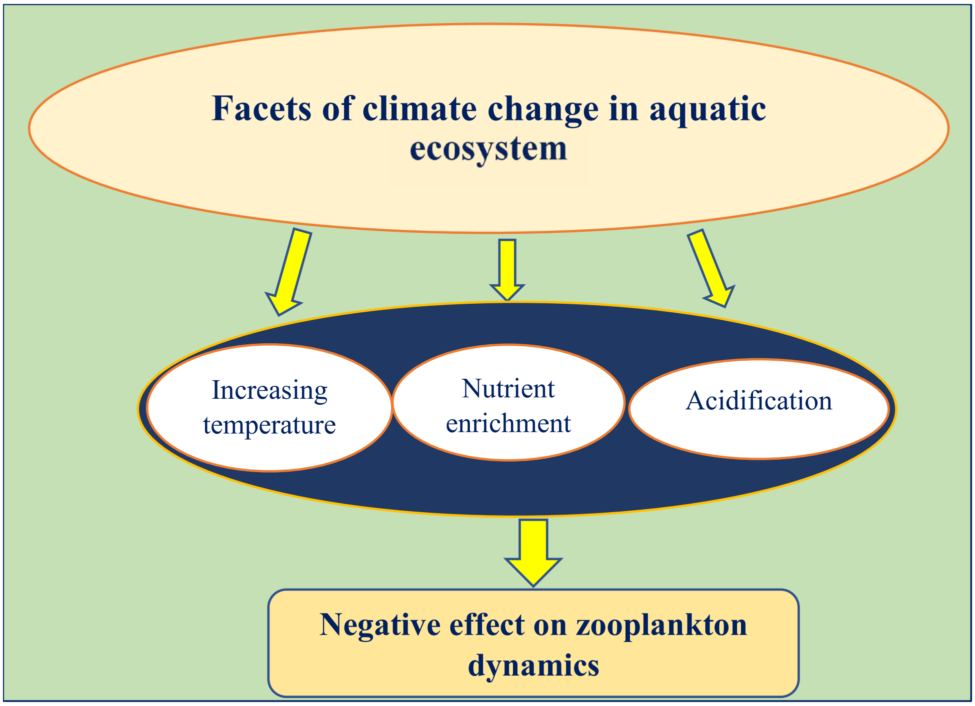

Fig. 1. Attributes of climate change affecting zooplankton.

Table 1. Various attributes of climate change affecting zooplankton

S. no	Climate change attributes	Effect on Zooplankton	Affected component of zooplankton	Reference
1	Increasing temperature in aquatic ecosystem	Behaviour	Alteration of grazing rate	Hu *et al*. (2018)[65]
			Disturbance in migration pattern	Jonkers *et al*. (2019)[66]
		Survival	Mortality in fourth instar or pupal stage	Hanazato and Yasuno (1989)[61]
		Growth	Rise in metabolic rate	(Rosenfeld *et al*. 2015)[70]
			Hypothermic stress	Khan and Khan (2008)[79]
			Reduction in body size	Havens *et al*. (2015)[80]
		Development	Size at maturity	Buns and Ratte (1991)[74]
		Reproduction	Decline in reproductive success	(Rhyne *et al*. (2009)[84]; Doan *et al*. (2019)[85]
			Decline in egg production	Ruiz *et al*. (2021)[86]
2	Nutrient enrichment in aquatic ecosystem	Fitness	Egg abortion	Bednarska & Slusarczyk. (2013)[124]
		Growth and reproduction	Low ingestibility for large algal particles	Porter and McDonough. (1984)[126]
		Diversity	Decline in survival	Bockwoldt *et al*. (2017)[133]
3	Acidification in aquatic ecosystem	Trophic interactions	Mortality of herbivorous zooplankton density	Murphy *et al*. (2020)[50]
		Life span	Impairment of reproductive maturity	Havens *et al*. (1993)[138]
			Decreased egg hatching	Invidia *et al*. (2004)[97]
		Calcification process	Negative effect on shell formation in planktonic calcifiers	Fabry *et al*. (2008)[142]
4	Change in ultraviolet exposure in aquatic ecosystem	Behaviour	Alteration in vertical migration of zooplankton	Balseiro *et al*. (2008)[168]
		Growth and fitness	Negative impact on molting process	Wolinski *et al*. (2020)[167]

sites, phytoplankton richness got reduced that indirectly decrease the diversity of zooplankton by diminishing resource heterogeneity (i.e., phytoplankton richness) therefore, providing evidence in favour of the model that shows damaging effects of cyanobacteria on zooplankton diversity.

Effect of Climate Change Induced Acidification and Response of Zooplankton

Due to climate change, a rise in CO_2 concentrations could be responsible for the acidification of freshwaters in crystalline and bed-rock areas that is similar to what is also predicted for the oceans[134]. It has been estimated that about 25 billion tons of CO_2 is released into the atmosphere each year[135]. Some of the studies focus on ocean acidification as well as carbon capture and storage activities that result from continued anthropogenic emission of CO_2 and the resulting acidification due to increased CO_2 absorption from the atmosphere, thus decreasing the pH of the water and subsequent alteration of ocean chemistry[136,137]. This increased acidity in the water bodies may also pose a deleterious effect on zooplankton communities**.** During the field survey and laboratory studies of various lakes in Ontario, the six common crustacean zooplankton taxa were analyzed for their acid sensitivity and were subsequently ranked wherein the ranking (from most to least sensitive) of zooplankton include, *Daphnia galeata mendotae, Daphnia retrocurva, and Skistodiaptomus oregonensis* > *Diaphanosoma birgei* > *Mesocyclops edax* > *Bosmina longirostris,* and the finding also predicted the widespread damage in the zooplankton community due to acidification in Ontario and North Eastern U.S. lakes[138]. The conditions of decreased pH caused by different means viz., ocean acidification due to climate change and carbon capture and storage leaks are found to significantly impact foraminifera, pteropods, and copepods[139]. Acidic environments are predicted to eliminate sensitive zooplankton species by impairing their reproductive maturity and increasing their death rates[138]. Significant mortality was also observed in the *Acartia tonsa* at pH < 6.7[140], whereas some of the experimental studies showed the effect of decreased pH (due to acidification) on some zooplankton species viz., *Acartia tonsa* a copepod that showed decreasing egg hatching and life span when exposed to pH below 6.5[97], *Calanus glacialis* showed a decrease in hatching success when exposed to pH of 6.9 for a period of 9 days[141] and negative effects on shell formation and calcification rate in planktonic calcifiers[142]. Ocean acidification is considered a major threat for numerous calcifying planktonic organisms (e.g., pelagic gastropods; *Limacina* spp.)[143]. Acidifications cause direct mortality to herbivorous zooplankton density, thus acidification together with warming alter the trophic interactions in planktonic community food webs from bottom and top[50]. Thus, overall findings also significantly predict detrimental effects of acidification of water bodies on zooplankton species in their wild habitats if the causal factors for climate change continue to remain operating.

Climate Change Induced Elevated Temperature and Change in Ultraviolet (UV) Response in Zooplankton

Due to climate warming, ultraviolet exposure has increased at mid to high latitudes[144]. Some important factors that play important role in UV exposure of planktonic organisms are, the timing and extent of ice cover as due to mixing of water after ice-out, the UV transparency is greater in water as compared to ice[145]. Climate change alters the lake thermal regime[146] and during recent decades, it has been observed that due to climate change the timing and extent of ice cover have changed as evident from the Northern Hemisphere lakes wherein the ice-out occurs 6.5 days earlier per hundred years[147] and in case of Arctic sea ice cover, the areal extent has also been decreasing significantly[148]. Due to these alterations in the extent and timing of ice cover around the globe, the thermal stratification process of lakes will change due to which there might be an altered UV exposure in lakes. It has been observed that the altered stratification can also lead to accelerated photobleaching and therefore the surface water of lakes shows increased UV transparency[149]. Some workers opined that due to stratification, the less motile plankton species are easily trapped in high UV surface waters. Since photo enzymatic repair (PER), a light-dependent DNA repair phenomenon provides a sort of tolerance against UV exposure in some zooplankton species but is absent or weak in some species[150]. Some workers somehow opine that UV: T (ultraviolet : temperature) ratios play an important role in UV tolerance in zooplankton

(Williamson *et al*., 2002)[151] and according to them, the DNA repair process will be decelerated and net DNA damage is increased during high UV:T ratios and vice versa. Therefore, the UV exposure shows its effectiveness as a function of ambient temperature which causes major threat to this important biotic community. Studies done by Williamson *et al.* (2002)[151] have shown that *Daphnia catawba, Leptodiaptomus minutus, and Asplanchna girodi* when exposed to UV-B at four different temperatures;10, 15, 20, and 25 °C, the *D. catawba* and *L. minutus* species showed increased UV tolerance at elevated temperatures that depend heavily on photoenzymatic repair (PER), but decreased UV tolerance in *A. girodi*, a species that has less PER. Also, the *Daphnia* showed a decrease in body size with increasing UV dose. Therefore, it may be concluded here that the altered thermal regimes and creation of underwater UV environment due to climate change and also the dependence of PER on temperature will result in trouble in the normal process of UV response in zooplankton. Extensive studies regarding the diverse behavioural responses of zooplankton to ultraviolet radiation (UVR) have been carried out by various workers[152,153]. There occur some significant adaptations of zooplankton with respect to UVR viz., avoidance of predators[154], ûight from UVR[155,156,157,] and grazing migration[158,159]. At times, the dissolved organic matter (DOM) in the aquatic ecosystem seemingly relieves the detrimental effects of UVR by absorbing UVR molecules[160]. Daphnids have compound eyes that possess the ability to recognize harmful UVR[161] and the first response they show towards the UVR is the movement into deeper waters[162,155,163,164], thus potentially eliminating the metabolic harm that could have resulted from UVR[165]. Another target of increased UVR in water bodies is the molting process of some zooplankton. Molting involves chitobiase (chitinolytic enzyme) and the process of apoptosis (caspase-3 activity)[166,167]. It has been found that UVR negatively impacts molting phenomenon in *Daphnia commutata* leading to its growth reduction, therefore changing its fitness and overall population dynamics[167]. Some reactive oxygen species are also produced due to UVR that can disturb vertical migration of zooplankton viz., *Daphnia commutata*[168], change its pigmentation[169], the integrity of DNA[170,] and activity of alkaline phosphatase[171].

CONCLUSION

Though knowledge about the effect of climate change on zooplankton seems scanty but climate change pose significant effect on the zooplankton as evident from the laboratory-cum field observations and the detrimental effects are likely to expand in near future. Since zooplankton act as a major link in the aquatic food webs and thus it may be predicted that if the causal factors of climate change continue to operate beyond their limits, then there is maximum possibility of a major shift in the aquatic ecosystem dynamics as far as its biota and stability is concerned. Various research problems taken in hand about the zooplankton dynamics must include their relationship with biotic and abiotic parameters that could provide a wide understanding of their response towards changing climate. In addition, there must be the reinforcement of the policies, which are meant to mitigate the factors responsible for climate change, with strong government support and political will, only then we can combat this war of climate change.

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Conflict of Interest

The authors have no conflict of interests to declare that are relevant to the content of this article.

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