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Climate change and earthworms: A global perspective

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Abstract
Climate is defined as the average of the weather condition over a long time, understood by observing and recording weather over a length of time. The observations of climate and climate change revolves around temperature and precipitation being the major parameters of climate that affects the earth and the living beings. Climate change is known to affect the soil ecosystem as well and therefore affect the soil living organisms. In this study we have tried to understand the effect of climate change on the earthworm fauna. Since earthworms are known as farmer's friends, and finds important role in agriculture, vermicomposting, increasing the plant production, maintaining and reconstruction the topsoil, is finds applications in organic farming and treatment of sewage sludge and tacking problems of climate change they prove to be important organisms of study. Since they are exposed to pollutants, insecticides, nanoparticle, and harsh climate conditions in soil we have tried to understand in this study, what role climate changes simulated by laboratory or field conditions play in (i) species distribution (ii) soil and interaction with other organisms and (iii) effect of pollutants under the impact of climate change on earthworm. It appears from the study that climate change affects the physiology of the earthworms and the nature and reaction of chemicals and thereby affect interactions and effects the physiology and biochemistry of earthworms. The future scope of this study lies in establishing earthworm as biomarkers of climate change.

Keywords: climate, earthworm, biodiversity, earthworms

Introduction

Climate includes the statistical analysis of weather over long period of time. While the major parameters of climate include temperature and precipitation, the other parameters include air humidity, direction and speed of wind, atmospheric pressure, cloud cover, solar radiation, atmospheric particle count and other meteorological variables over long periods of time in a defined region. The rise in temperature of the earth due to increase in greenhouse gases generated from anthropogenic activities are a major problem and global climate change is a major concern across the world. In the Arctic zones, the study of snow and ice cover are important parameters inferring about climate over long periods of time and their study finds importance from the environmental monitoring point of view. Climate change is known to affect soil ecosystem also. The study of temperature changes and intense or extreme weather conditions, is important from the ecotoxicological point of view since it acts as a stressor and affects the physiology of the organisms. The changes of climate is known to impact the ecosystem and could potentially affect the production of wood products, crops, livestock, and game and impact the biodiversity and species extinctions (Loehle, 2011) [21]. The rise in temperature can lead to rise in the sea levels and with oceans becoming warmer and with increasing droughts there is a potential threat to crop production, growth and survival of wildlife and freshwater supplies. Climate change is known to affect the biodiversity of polar bears in the Arctic, marine turtles off the African coast, birds, animals and threatens existence of other species and livelihood of people. Behavioural and physiological changes in birds like early egg laying in the year than usual, early blooming of plants, animals with shorter hibernation periods, affected distributions, species moving closer to the poles, altered pattern of migration of birds and arriving earlier at their nesting grounds, loss of nesting beaches of sea turtles due to rise in sea level by of only 50cm, stop of the migratory flights of Wildebeest in several African countries, affected migrations of fish, mammals and water birds that migrate up river to breed and spawn are affected due to changed rainfall patterns, causing to building of dams is alarming. It is thought that many migratory and non-migratory species may become extinct in the near future.

Although earthworms (Figure 1) are primitive animals belonging the invertebrate Phylum Annelida, they are robust organisms containing the unique metabolite drilodefensins in their gut that protect them against plant polyphenols (Liebeke *et al*, 2015, Ghosh, 2018) [21, 10, 11] and enable digestion of the dead plants through their guts, together with, although primitive but a robust immune system. They find importance in restoring degraded soils and plays role in creating healthy soil (Blakemore and Hochkrich, 2017, Davies, 2017) [2, 17], with their activity affecting both biotic and abiotic properties of the soil, in turn affecting plant growth, mineralising nutrients, either directly or by stimulating microbial activity therefore playing role in increasing the yield of crops. (van Groenigen *et al*, 2014) [33] Rain filtered through worm burrows leads to the generation of worm humus that both stores moisture and can sustain crops through drought (go.nature.com/2oofvfq) [12], thus holding great promise in solving problems in climate change in rebuilding the topsoil, reducing needs of agrochemicals and boost carbon storage in soil through ingestion of plant remains (http://4p1000.org). But several of their members are facing risks of extinction and are recorded in the undergoing in the Red List of the International Union for Conservation of Nature therefore the reasons to their extinctions needs to be studied in greater details.

Recently one new species of earthworm *Perionyx shyamasreetus* has been reported and collected from Bhubaneswar district of Odisha India (Latitude 20.3119° N and Longitude 85.8606° E). This species has been reported to belong to the family of Megascolecidae with 9 genus reported from India and genus, *Perionyx* with 42 species reported from India (Ghosh *et al,* 2018) [10, 11].

Fig 1: Earthworm (*Metaphire posthuma*) Collected from Kolkata, India

Although some studies report about the effect of climate change in organisms exists no comprehensive study exists to understand the impact of climate change on soil organisms like earthworm that are helpful to the farmers as natural tillers of the soil and other benefits for human and plant life. In this report we study the impact of climate change on (i) species distribution and soil habitat of earthworms (ii) invasions (iii) effects of pollutants in presence of altered climatic conditions.

Climate change and impacts of species distribution and soil habitat of earthworms

Climate change could affect directly the animal population and indirectly the animal life by affecting the chemicals and their interactions with cells and tissues which bear impact on animal life. Climate change has been reported to affect soil ecosystem, invasions of organisms and affect interacting organisms and lead to altered pesticide effect. Climate change simulated by increase in soil moisture could increase toxicity of mercury (Hg) on earthworms and enchytraeids affecting survival and reproduction rate (Buch *et al,* 2017) [3] indicating that climate change affected the toxicity of elements in soil thereby affecting earthworm indirectly.

Altered invasions and affected interaction in ecosystem

Biological invasions pose a serious threat to biodiversity and ecosystem functioning. Invasion by anecic and endogeic earthworms, in previously earthworm-free ecosystems has been reported to alter the physico-chemical characteristics of the soil and cause a significant decline of the diversity and density of soil invertebrates (Ferlian, *et al,* 2018) [8]. Two major clades of earthworms (Crassiclitellata) reveal Pangaean distributions (Anderson *et al,* 2017) [1] although whether climate change played a role remains unknown. Climatic gradients are known to affect ecosystem interactions. (Veldhuis *et al,* 2017) [34]. Plant diversity significantly declined in North American forests with increasing richness of introduced earthworm ecological groups and that plant species adapted to the abiotic conditions of earthworm-invaded forests (Crven *et al,* 2017) [4]. Again invasion of earthworm has been reported to have beneficial effects. Anecic earthworms *Lumbricus terrestris* and euedaphic collembola, of the soil fauna feeding on plant litter increased litter-derived N_2 emissions in the loamy soil, creating hotspots for denitrification, and enabled the production of bioenergy in perennial agroecosystems (Schorpp *et al,* 2016) [26] by natural process thereby increasing the soil fertility and making it suitable for better and higher plant produce. The invasion of European earthworm species across northern North America has revealed severe impacts on native ecosystems. While long and cold winters led to slowed earthworm invasion, future warming is hypothesized to accelerate earthworm invasions into yet non-invaded regions. But warming has been reported to induce reductions in soil water content (SWC) thus decreasing the earthworm densities, biomass and performance and thus warming caused unfavourable soil abiotic conditions and restricted earthworm invasion in northern North America without increased rainfall compensating the water loss from evapotranspiration (Eisenhauer *et al,* 2014) [7]. Earthworms can modify soil structure and nutrient availability, and hence alter conditions for plant growth through their burrowing and casting activities (van Groenigen *et al,* 2014) [33, 37] and climate change may affect these activities.

Altered pesticides effects

Increase in the temperature or altered precipitation and soil moisture could either enhance or lower toxicity of pesticides including fungicide - propiconazole (PCZ) and an insecticide - chlorantraniliprole (CAP) and has been reported to affect biochemical biomarkers in *Eisenia fetida (E fetida,* Table 1*)*. The physiological and biochemical characteristics were indicative of the fact that climate change played important role in altered effects of pesticides on earthworms (Hackenberger *et al,* 2018) [15]. Accumulation of metal/metalloid As, Cd and Zn from polluted soil revealed

differences due to changed parameters of climate including global warming with increasing air temperature and decreasing soil moisture reported from on *Eisenia andrei* (*E. Andrei,* González and Alcaraz, 2016 [13], Table 1).

Table 1: Species

Species	
Alnus incana	*A incana*
Athene noctua vidalli	*A n vidalli*
Betula pubescens	*B pubescens*
Brassica rapa	*B rapa*
Eisenia andrei	*E andrei*
Eisenia fetida	*E fetida*
Folsomia candida	*F candida*
Julus scandinavius	*J scandinavius*
Lumbriculus variegatus	*L variegatus*
Lumbricus rubellus	*L rubellus*
Lumbricus terrestris	*L terrestris*
Metaphire guillelmi	*M guillelmi*
Microscolex dubius	M dibius
Oniscus asellus	*O asellus*
Perionyx shyamasreetus	*P shyamasreetus*
Pimephales promelas	*P promelas*
Rhinodrilus alatus	R *alatus*
Triticum aestivum	*T aestivum*

Silver nanomaterials including AgNP and $AgNO_3$ as soil pollutant, could affect earthworm survival and reproduction reported in *E.andrei*. (Velicogna *et al,* 2016) [35]. Earthworms *E fetida* grown on DDT contaminated soil revealed increase in mortality, growth inhibition rates, high glutathione-S-transferase (GST) and the oxidative defense enzyme catalase (CAT, Shi *et al,* 2016) [29]. Biochar application for bioremediation of soil polluted with hydrophobic organic pollutants, 2, 4-dichlorophenol and phenanthrene when treated on earthworm *M guillelmi*, biochar could not decrease the bioaccumulation of the pollutants and the metabolites in soil by the earthworm and thus inferring that biochar may not be appropriate in soil remediation of polluted soil by hydrophobic organic pollutants (Gu *et al,* 2016) [14]. Polychlorinated biphenyls (PCBs) and perfluorinated carboxylates and sulfonates (PFASs) have been reported to bioaccumulate in *Hexagenia spp., Lumbriculus variegatus (L variegatus) and Pimephales promelas* (*P. Promelas,* Proser *et al,* 2016 [24], Table 1).

Temperature affected the toxicity of pollutants and the physiology of the organisms and thus temperature change can cause toxic effects of pollutants present in soil ecosystems. Earthworms *E. fetida* tested with pesticides under different exposure temperatures of 15°C, 20°C and 25°C reveal that toxic effects of the pollutant increased with increase in temperature (Velki and Ečimović 2015) [36]. Tetrabromobisphenol A (TBBPA), hexa bromo cyclo dodecane (HBCD) and decabromodiphenyl ether (BDE 209), affected growth, altered the superoxide dismutase (SOD), catalase (CAT) and the stress-response gene involved in the prevention of oxidative stress (Hsp70) of earthworms *E fetida* (Pereira *et al,* 2015) [23]. The giant earthworm, *Rhinodrilus alatus* (R *alatus*, Righi 1971) [25], in the southeastern Brazilian Cerrado is the only species extracted for trade and the extractors have revealed impacts of climate change on the species and accordingly capture techniques vary with dry and rainy seasons (Drumond *et al,* 2015) [6].

Earthworm abundance and diversity in a 16-year old grass sward, a 6-year old Plantation and a 4-year old Plantation, and in remnant woodland, in suburban Sydney, Australia, revealed the occurrence of more earthworms in spring than in winter or summer, with nil in autumn, indicative of the fact that climate variation affected earthworm abundance. Exotic species, mostly *Microscolex dubius (M dubius)*, dominated in all the vegetation covers while the only two native species (*Heteroporodrilus* sp. And *Megascoleceides* sp.) found were in the woodland. (Morales *et al,* 2013) [22]. Mineral nutrient contents and soil pH were found to be the major factors controlling earthworm reproduction, cocoon formation and gain of body weight. (Morales *et al,* 2013) [22].

M guillelmi in presence of 5% biochar treated soil enhanced the minerarilisation of (14) C-catechol and revealed assimilation of biochar-associated (14) C-catecholic residues (Shan *et al,* 2014) [26]. The toxic effects of the pesticide carbaryl tested in different temperatures simulating the temperate and tropical climates and climate change predictions or seasonal temperature fluctuations on *Folsomia candida (F. candida), E andrei, Triticum aestivum (T aestivum) and Brassica rapa* (*B rapa*) revealed synergic effects in high temperature and antagonism at low temperatures. At high temperatures, carbaryl toxicity decreased *F. candida* reproduction indicative of the fact that high temperature increased deleterious effects of pollutants like carbaryl in earthworm. *T aestivum* showed to be less affected when exposed to increase or decrease in temperatures. (Lima *et al*, 2015) [20]. *M guillelmi* significantly decreased formation of bound residues of 4-NP (nonphenol) in the soil. (Shan *et al*, 2014) [27].

Warmer climates, are known to influence the replacement of boreal tree species by temperate species in the southern boreal forest, together with replacement of small detritivores replaced by larger exotic earthworm. European earthworms favour seedlings of boreal tree over temperate species, thereby causing hindrance to their northward expansion. Warming-induced changes in consumer community, and above- and below-ground cascades of trophic interactions that enable persistence of boreal tree in early phases of warming, indicating that consumers can modify the climate change-induced transition of ecosystems (Frelich *et al,* 2012) [9].

Low decomposition rates enable high-latitude ecosystems to store large amounts of carbon and harsh abiotic conditions and absence of macro-detritivores hinders proper decomposition. Litter of *Alnus incana (A incana)* and *Betula pubescens* (*B pubescens*) incubated in microcosms together with monocultures of three functionally different macro-detritivores including earthworm *Lumbricus rubellus (L rubellus)*, isopod *Oniscus asellus (O asellus)*, and millipede *Julus scandinavius* (J *scandinavius*) revealed that macro-detritivores stimulated decomposition of high-quality. A. incana litter revealed maximum decomposition by earthworms indicating that climate change-induced range expansion of macro-detritivores into subarctic regions may lead to accelerated decomposition rates and the biomass but not species or number of the macrodetritivore regulates the magnitude of macro-detritivore mediated subarctic decomposition (van Geffen *et al,* 2011) [32].

Global climate change is predicted to alter the diversity and community composition of soil fauna, affecting in invertebrate species diversity affecting fungal-mediated decomposition. Abiotic climate change factors including CO_2 and temperature affect mycelial productivity directly, and indirectly cause changes in the soil invertebrate community. (Crowther *et al*, 2011) [5].

Soil organisms, including insect and oligochaete burrows reveal increased abundance during the The Paleocene–Eocene Thermal Maximum (PETM), suggesting longer periods of soil development and improved drainage conditions. Smaller body sizes due to higher subsurface temperatures, lower soil moisture conditions, or nutritionally deficient vegetation in the high-CO_2 atmosphere inferred for the PETM, is indicative of the fact that over the last 150 years of increased atmospheric CO_2 and surface temperatures have led to reduced size over the next century and it is proposed that soil fauna across the Permian-Triassic and Triassic-Jurassic boundary events show significant size decreases as a consequences of global warming (Smith *et al,* 2009) [30]. Thus emphasising the fact that temperature is a major parameter of climate change globally affecting lives of organisms. *Lumbricus terrestris* (*L terrestris*) acclimated at 10-12^{0}C i.e., 2^{0}C above their habitat temperature showed about 5% increase in rate of oxygen (O_2) consumption, which increased with temperature till 20-22^{0}C when in the acclimatised worms it showed decrease by 84%. Temperature also increased the blood hemoglobin (Hb) concentration, which decreased slightly in 20-22^{0}C -acclimatised worms with hypovolemic blood indicating dehydration. Pre-exposure of 10-14^{0}C-acclimated worms to sublethal concentrations of heavy metals including zinc (Zn), copper (Cu), lead (Pb) did not significantly affect the rate of respiration while it was affected in earthworms acclimatised in 20-22^{0}C with lowered oxygen affinity of Hb and shifts in carbon monoxide (CO) content, limiting the aerobic metabolism indicative of effect of global climate change on earthworm physiology (Khan *et al,* 2007) [18].

Fertile ecosystems of river floodplains enable enhanced growth and reproduction of earthworms, serving as food for food to badgers (*Meles meles, M meles*) or little owl (*Athene noctua vidalli, A n vidalli* species). Flooding, is known to reduce earthworm numbers with the flood surviving coccons giving rise to populations after flood subsides but cocoons cannot develop into adults in short interim periods in between flood and populations cannot sustain. Flooding frequency and flood plain rehabilitation has been observed to be an important parameter of climate change that can control the viability of earthworm populations as reported from a study on model *L. rubellus* earthworm in a Dutch floodplain; the Afferdensche and Deestsche Waarden along the River Waal in Netherlands. Together with flood frequency and rehabilitation period, exposure to soil contaminants may further suppress earthworm viability (Thonon and Klok 2007) [31] emphasising the fact that floods as parameters and consequences of global climate change can affect earthworm survival.

Conclusion

Thus although earthworms are of major importance as natural tillers of the soil, removing the soil debris, helping in increasing in soil fertility, enabling bioremediation of soil by also helping in increase in soil fertility, and solving many problems in climate change are themselves being affected by parameters of climate change. The rising global temperature and affected rainfall are concern globally and also known to affect the earthworm lives in the soil ecosystem also. Although an exhaustive study is far from complete to infer at the exact effects of climate change on earthworms, studies from different part of the globe in diverse ecosystems and habitats have concluded that global climate changes has detrimental effects on earthworm. We report conclusively that direct effects of global changes and also indirect effects of heat on pollutants affect the earthworm physiology, distribution, invasion, reproduction and life. As a consequence of human interventions, anthropogenic effects and climate change, many of the species are already becoming extinct globally. Therefore every effort should be taken to rescue the earthworms from the detrimental effects of pollutants and climate change parameters. The future scope of this article remains in trying to trace whether earthworms could be used as agents in environmental monitoring of climate change and to save them from climate change induced damages.

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