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Implications of global changing climate on forensic insects in the tropics: A review

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Abstract
The analysis of climate change effects on forensic insects is grossly neglected in the tropics and requires attention. It was revealed that insects associated with cadavers at different climatic regions experience accelerated or delayed developmental activities. As a consequence, global warming pushes species that are resident in southern hemisphere to the northern hemisphere and predispose some susceptible indigenous species to extinction. The southern species are likely to benefit from this phenomenon by increasing their range, facilitating their activities and completing their life cycle earlier than before. Global warming is capable of altering the accuracy of postmortem interval of a cadaver if forensic insects recovered on body are not carefully examined. Time-base disparity in estimating postmortem interval of a body is a perceived repercussion accentuated by climate change in the tropics and across the globe. It was also revealed that climate change will incontrovertibly change the biological clock and range of forensic insects. In Nigeria, the early arrival and shorter life cycle of forensic insects on exposed cadavers and faster decomposition in the southern region, could lead to questionable postmortem interval of cadavers if the sequence of events of cadaveric fauna of the regions are not harnessed and properly documented taking into account the changing climatic variables. Climatic variables of temperature, relative humidity, volume of rainfall, speed of wind and light intensity can also greatly influence population dynamics of forensic insects by modulating their survival, rates of development, fecundity and spread.

Keywords: Cadavers, climatic regions, global warming, forensic, postmortem interval

1. Introduction

Terrestrial ecosystems are mainly steered by arthropods especially the insects; but because they are generally small, their lives are inevitably connected to ambient temperature [1, 2, 3, 4] which fluctuates naturally. The influence of fluctuating temperature has been noted by researchers; that it affects the population dynamics and distribution of diverse insect species including insects of forensic relevance [5, 6, 7]. Unequivocally, the survival, physiology and adaptation of insects are influenced by temperature extremes occasioned by climatic variations [8, 9, 10].

Therefore, climatic variables such as temperature, relative humidity, volume of rainfall, speed of wind and light intensity influence insect population dynamics by modulating their survival, rates of development, fecundity and spread. The report of the locust outbreaks in China, is correlated to drought and flood frequencies and low temperature regime based on evidence of long-time data collected for above 1000 years [11, 12, 13]. Based on the report of Intergovernmental Panel on Climate Change (IPCC), any climatic change beyond the tolerance level of animals especially the invertebrates may result to changing the time-frame of their life cycles and the size of their boundaries. It may also change their density, morphology, and their reproductive pattern or even lead to extinction of vulnerable species [14]. These physiological phenomena are attributable to either one these; humidity, intensity and periodicity of rainfall, solar radiation, elevated carbon iv oxide (CO2), ozone (O_3) and ultraviolet light level involved [15, 16, 17, 18] or occasionally by a combination of all of them. Temperature has been particularly implicated as the continual fluctuations of this abiotic factor have culminated in physiological and behavioural changes of animals, including insects. As insects are ectothermic, their life processes show a high level of sensitivity to air temperature as they respond swiftly to any rise in temperature [19, 20]. Temperature limits, usually restrict some insect species to a particular geographical range and mark their boundaries. For instance, climatic isotherms are reported to have moved 120 km on the average during the past 100 years towards the north. Thus, about 63% of non-migratory butterflies in Europe have stretched their spread by 35-240 km toward the north [21]. It was mentioned in the fourth IPCC report that the progressive appearance of butterflies, increased fecundity of some species, genetically modified changes in morphology and life history characters, caused extinction of some species and expanded damage pattern of forest because of bark beetles in the USA and pine processionary moths in Europe. Changes in the range of vector-borne diseases mainly in the tropics are anchored on temperature changes too [22].

Increase in population abundance of native species and facilitation of spread of alien species are usually triggered as an outcome of climate warming [23, 24]. These biological changes in insects are well noted at higher altitudes and latitudes [25]. Response to mean temperature rise owing to climate change, is possible to be specific to regions and beside, insect species react differently to climate warming. Notably, within species or population, their response may be different between life history characters, seasons and bioclimatic regions [26, 27, 28, 29, 30].

To fully understand the impact of climate change on insects, it is sacrosanct to consider the whole life cycle of insect species in question to ascertain the complete disruption. When the range modifications and or phenological adaptations about insect responses to global warming have been tried it is still difficult to predict the result of future temperature upsurge on insect populations [31, 32 33, 34]. Thus, global warming affects all the organisms concurrently in every defined community (vegetations, preys, predators, mutualists and symbionts) leading to multiple flowing effects on insects, resident on that community [35, 36, 37, 38, 39]. This entomological communication is worthy of note.

Insects are globally impacted either by circumstances produced during and after environmental instabilities whereas some species with life-history traits will show some level of tolerance to the instabilities [40, 41]. Their responses influence their interactions with other organisms within a community leading to conducts and the extent of energy and nutrient fluctuations within the system [42]. The way insects respond to environmental instabilities will determine how they will respond to anthropogenic changes, habitually with stern consequences for their beneficial services in the environment [43].

Based on the current global estimates of climatic changes with capacity to significantly affect insect development and their distributions, an upsurge in temperature which persists over a stretch of years will have many implications on temperature-dependent species. For instance, an upsurge in global mean temperatures of 1ºC by 2025 and 3ºC towards the end of another 100 years will affect many biological organisms [44]. Therefore, change in climate within a 10-year time scale, will influence the timing and frequency of insect outbreaks and this is capable of changing their distributions. Based on spatial modelling technique to predicting how a continued climate change would modify the distribution of species geographically by simulations, maps that show predicted shifts of zones, where experimented species expanded their range in 1-year and on 10-year intervals have been presented [45]. Klok and Chown [46] have evaluated the relationship between temperature tolerance and phenology of insects and opined that increased temperature and decreased rainfall affect physiological regulations and susceptibilities species. Though, insects are biological components of every ecosystems, they will however be impacted by climate change in various ways including those which are yet to be ascertained by scientists [47]. This point should not be neglected. In Africa, environmental disturbances such as altered fire regimes, construction and expansion of roads, release of toxic materials such as oil spills and discharge of industrial effluents are accentuated by man. Insects respond to these pervasive environmental disturbances directly or indirectly the way they respond to natural disturbances. For instance, forest-harvest may trigger responses that are similar to canopy-opening disturbances [48, 49] while anthropogenic changes may aggravate the effect of natural disturbances. Clean clearing of land and destruction of reservoirs for agriculture and other purposes have taken place concurrently over a large area of landscape in Africa. These practices have led to increase warming of the region, intensifies storm, runoff water and stream discharge. Therefore, the mean return time for flood of 100-years severity is expected to shrink to 30 years [50] by estimation. The continuous removal of vegetation, and smoke from illegal oil refineries, and from fires associated with forest conversion to agricultural or urban land use, is becoming alarming in Nigeria, a tropical nation. These practices are reported to reduce cloud cover from 38% in clear air to 0% in heavy smoke, and increase the altitude where water condenses, causing violent thunderstorms and warm rain [51, 52, 53]. The amplified incidence of this life-threatening disturbances leading to global warming of the climate will affect insects and other organisms, though practically difficult to predict exactly when and magnitude of impact [54]. Uncertainties are growing concerning the droughts that are getting worse in the arid zones of the tropics, leading to water and food insecurity. In northern Nigeria, large expanse of land mass is getting drier while in the southern, the whole region is becoming wetter almost all through the year. Thus, while the greater parts of the north would be getting drier, the whole south would be getting wetter and would mimic humid-tropic condition. These climatic variations that usually occur in the extremes would inadvertently make drought and flooding a persistent occurrence in the northern and southern regions respectively [55]. These changes will greatly concern insects of forensic importance in several ways, but unfortunately, this has been poorly documented.

2. Forensic considerations

Insects associated with cadavers are primarily aiding their decomposition by eating body flesh. The arrival and presence of forensic insects on cadavers are predictable and in succession [78]. Their predicted time of arrival and succession pattern on cadavers are useful in forensic science as they aid to approximate the postmortem interval (PMI) of the questionable body. The PMI of a body is the elapsed time between the time of death or last seen alive and time of discovery [56]. Thus, their usage to estimate PMI of a body is referred to as forensic entomology. It is the study that focuses on insects and other related arthropods in a legal dispute [57]. It is broadly applied in three categories; urban entomology (i.e. litigation relating to insects and human environments, e.g. insects destroying woods in the house], stored-product entomology (i.e. litigation relating to insects and food products in store) and medico-legal entomology or medico-criminal entomology (i.e. criminal investigation relating to a violent crime or questionable death using insects as evidence) [58, 59]. Medico-criminal entomology is utilized in several circumstances involving both domestic negligence of elderly people and infants, child abuse and homicide [60, 61]. It can as well be useful in exploring wildlife poaching and trace movement of vehicles by identifying insects trapped on the windscreen and relocation of cadaver and recognition of gunshot remnant [62, 63, 64, 65]. The most interesting and highly practiced, in forensic entomology remains the estimation of elapsed time between time of last seen alive or death and time of discovery, using insects recovered on cadavers and recently using the recovered insects as toxicological samples [66, 67].

Insects associated with decomposing cadavers are grouped into four; namely, species that are necrophagous in nature-they eat the tissues and organs of the body, the predators and parasitoids of the necrophagous species, the omnivorous species that eat equally the cadaver and every other invertebrate resident on the body of the cadaver and the adventive species that act as local entomofauna within the cadaver [64]. The necrophagous species afford the most consistent information as regards the time of death because as they are the first colonisers of cadaveric bodies. They are mainly dipteran blow fly species in the family Calliphoridae with four distinct stages of development (egg, maggot, pupa and adult) [68] and coleopteran beetle species in the families of Dermestidae and Cleridae [64, 78]. The blow fly maggots provide the most useful information about the time of death and their bodies are very useful for toxicological analysis when the body has badly decomposed.

3. Implications of global climate change on insects of forensic importance

Blow fly species arrive on cadavers within minutes to a few hours after death depending on season and geographic location of the body. When they arrive on the cadaver, they either feed on the body fluid very rich in protein or the gravid females begin to lay eggs immediately on the body. The eggs are preferentially deposited in the nose, eyes, mouth and may also deposit eggs in the anus and genital opening if they are both accessible. The orifices provide moist, humid voids which enhance eclosion of eggs and survival of maggots that hatch thereafter. The maggots congregate in clusters to form maggot mass thereby generating their own temperature that is dissimilar to the ambient temperature. The number of eggs laid on the cadaver may be affected by the weather condition of the area. For instance, during colder months their numbers may be lesser and would be hidden under the eyelids or within the nostrils [69]. Changes in climatic conditions have great impact on the development of eggs, maggots and pupae. Therefore, for accurate PMI of a cadaver to be estimated, data such as ambient temperature and relative humidity, precipitation and wind speed or direction of the area must be collected and critically evaluated [69].

A glaring report of the 20th century showed that the world's climate has experienced 0.6ºC warming between 1910 and 1945 and from 1976 till date [71]. The upsurge in temperature for the last 30 years within the past 1000 years has been tremendous. For instance, the temperature variations of the Mediterranean basin and the Italian climate have increased in relation to global climate warming. Thus, the thermic-buffer power of the Mediterranean Sea is playing a part to land surface warming whereas; the Italian region is getting hotter because, the barrier created by the Alps which differentiates the peninsula from continental Europe is slowly being warmed [70]. There is a hint that unceasing warming of the climate is impacting wide range of organisms. The distribution of species in the southern hemisphere is extending to the northern hemisphere while the northern species have slim opportunity of extending into new higher altitudes; hence, they are restricted to tranquil places capable of leading them into extinction [70].

Apparently, thermophilous species at medium and elevated altitudes in Italy was due to recent changes in range and adaptations of new species to the new areas. Their assertion was based on comparing new species with the species preserved in the museum. They further submitted that in mountains; valley animals are extending to higher altitudes with greater speed than the isothermal extension of 8 to 10 metres in 10 years. This is happening because, the high-altitude of glaciers has receded, thus making pioneer species to extend their range and colonise newly discovered areas [70].

Based on range extension, forensic entomology in Italy has shown that newer insect species from different continents are gradually spreading and being associated with cadavers in the region. These species include the black soldier fly, *Hermatia illucens* Linn. In the family Stratiomyidae from the tropical region of America which was first reported in Italy in 1956 [72]. Today, it has gain prominence in the northern Italy at about 1300 metres above the sea level. The black soldier fly maggots are resistant to pesticides hence, they breed on pesticides treated cadaver exposed in the field and have been reported to predate on necrophagous species that earlier inhabited the cadaver especially, the blow fly maggots [73, 74]. Similar observation was recorded in Nigeria, as black soldier fly maggots found on rodenticide intoxicated pig cadavers predated on other fly maggot species and remained on the cadavers for a about 100 days [78]. Other species that have extend their range into the northern Italy include; *Tachinaephagus zealandicus* (Hymenoptera: Encyrtidae), an allochthonous species found on an indoor homicide case. It is a small parasitoid wasp from Australia that was employed to control fruit flies and myiasis in Africa and America, and *Hydrotaea capensis* (Diptera: Muscidae), a necrophilous species that was found breeding on indoor cadavers [75]. The work of Turchetto and Vanin [70] extensively accented that the above phenomena was as a result of global rise in mean temperature; therefore, making temperature dependent species such as insect species to shift from their cool boundaries, and spread from the southern hemisphere to northern hemisphere and from lowlands to higher elevations. Therefore, part of the forensic implications of global climate change on cadaveric insects is that, species modified to lower temperatures at the mountains or northern lands will have few suitable habitats to colonise (as local entomofauna of that habitat) or otherwise go into extinction. Contrarily, warming of the climate globally helps species colonising the tropics and subtropics to survive and disperse with ease especially, the species that have the capacity to modify their cycles seasonally and have the ability to travel far [76, 77].

Cadavers are inevitable baits that attract variety of insect species with cosmopolitan dexterity, they are therefore considered as energy spot in an ecosystem [70]. Forensic insects are also rapidly changing their range due to climate warming, so precautionary measures should be employed while using insects as a PMI tool. For instance, the time of eclosion of egg or laval pupation may be altered due to change in range and precipitation [70] of a specific area. This advocates that regional forensic entomology will suffice any interpretation relating to PMI of any corpse in this present time when the impact of global climate warming is a top discussion among environmentally concerned researchers.

Chrysomya albiceps is a known blow fly species regularly reported on decomposing cadavers of the tropical region, but its spread towards the northern hemisphere precisely in the Northern Italy [79, 80, 81] and its demographic explosion is a validation of the impact of global climate change on forensic insects [82, 83, 84]. In other words, climate change may impact on the identities of insects useful in forensic science in different regions making reference on deoxyribonucleic acid (DNA) analysis. It was stated that the *C. albiceps* maggots in Africa and South America which were morphologically identified, revealed to be 100% *C. albiceps* and approximately 98% *C. rufifacies* when subjected to DNA processes of identification [85, 86, 87]. A necessary deduction is that it is imperative to appreciate the source of species and their dispersion by meticulously checking if the body has been transferred from a long distance [79].

The key aspect of medico-criminal component of forensic entomology remains the estimation of PMI of a questionable death. However, the critical factor surrounding it is to discern the pattern and sequence of insects that are found on the cadaver, taking cognizance of the environmental variables of the area in question. Insects are cold-blooded animals; hence their metabolism and activity are highly impacted by temperature of their bodies which are directly influenced by their surrounding temperature. It has been remarkable that low temperatures constrain insect activities while higher temperatures arouse their activities [88, 89]. Bearing this in mind therefore, means that forensic entomologist should understand the trends associated with global climate warming in relation to cadaver decomposition and their associated insects at regional level. The impact global climate warming would have on insects have been sufficiently documented for lepidopteran species and dipteran vectors- mosquitoes, sand flies, tse-tse flies, feas [90]. By extrapolation, the way global climate warming would affect insects of forensic importance would not be different either; therefore, the precision of estimated PMI of a cadaver may be altered when insects are submitted as a PMI tool without considering variability that may emanate due to climate change. In some tropical countries, the impact of change in the global climate on the insect phenology has empirically not been evaluated. On the premise of ambient temperature and humidity in eastern Nigeria, it was observed that 22kg pig cadavers decomposed faster between 10 and 14 days, during rainy and dry seasons respectively and arrival of blow fly species within minutes and laying of their eggs observed within 30 minutes [78] at a mean temperature of 29 ºC and a relative humidity of 61.8%. Therefore, while temperature variations may delay arrival of insects on cadavers in temperate regions, it would accelerate their arrival on cadavers in the tropics because of continued high temperature that persists all through the year and moderate annual rainfall that are evenly spread especially in the southern region [91]. This scenario is not much different from the earlier arrival and faster development (egg to adult within 8 days) of blow fly species on pig cadavers in Okija, southeast Nigeria [92]. Therefore, if without genetic evolution, warming of the climate to about 3ºC will fast-forward the butterfly appearance for about three weeks [93] is extended to blow fly species in the southeast Nigeria, it means that completing their life cycle within one week on exposed cadavers would suggest that climate change has impacted on their life cycle.

4. Conclusion

Forensic insects at different climatic regions and seasons may experience accelerated or delayed development. Global warming may push species that are resident in the southern hemisphere to the northern hemisphere. It can predispose some vulnerable indigenous ones to extinction. The southern species are in addition likely to benefit by increasing their range, facilitate their activity and complete their life cycle earlier than before. Warming of global climate is a threat to living organisms on earth, including insects of forensic importance. It can alter the accuracy of PMI of a cadaver if insects recovered on body are not carefully examined. Therefore, time-base disparity in estimating PMI of a body is a perceived repercussion accentuated by climate change across the globe. Climate change will affect the biological clock and range of forensic insects and this is of great concern in the tropics.

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