Journal of Entomology and Zoology Studies

Available online at www.entomoljournal.com

JEZS Journal of Entomology and Zoology Studies

Environmental effects on insects and their population dynamics

A. Khaliq, M. Javed, M. Sohail, Muhammad Sagheer

ISSN 2320-7078
JEZS 2014; 2 (2): 1-7

Received: 06-02-2014
Accepted: 12-03-2014

A. Khaliq
Department of Agricultural Entomology, University of Agriculture, Faisalabad, Pakistan.
E-mail: abdulkhaliq1931@gmail.com;
Tel: +923444667987

M. Javed
Department of Agricultural Entomology,
University of Agriculture, Faisalabad, Pakistan.
E-mail: mudassar_560@yahoo.com
Tel: +923026409218

M. Sagheer
Department of Agricultural Entomology, University of Agriculture, Pakistan.
E-mail: sagheersharif@yahoo.com
Tel: +923338360262

Mubasshir Sohail
University College of Agriculture, University of Sargodha, Pakistan.
E-mail: mubasshirsohailroy@gmail.com
Tel: +923217963946

Correspondence:
A. Khaliq
Department of Agricultural Entomology, University of Agriculture, Faisalabad, Pakistan.
E-mail: abdulkhaliq1931@gmail.com;
Tel: +923444667987

ABSTRACT

Insects are powerful and rapid adaptive organisms with high fecundity rate and short life cycle. Due to human interruption in agro-ecosystem and global climatic variations are disturbing the insect ecosystem. Erosion of natural habitats, urbanization, pollution and use of chemicals in agro-ecosystem manifold the intensity of environmental variations. Both a-biotic (temperature, humidity, light) and biotic (host, vegetative biodiversity, crowding and diets) stresses significantly influence the insects and their population dynamics. In response to these factors insect may prolong their metamorphic stages, survival and rate of multiplication. Insect's immune responses as melanization, lysozyme level and phenoloxidase (PO) modify the physiology and morphological behavior against different factors like diets, gases and chemicals.

Keywords: *Gymnopleurus,* Karyotype, Chromosomal rearrangements, Scarab beetle.

1. Introduction

Global changes are responsible for wide range of anthropogenic and natural environmental variation [27]. These climatic and weather changes not only affect the status of insect pests but also affect their population dynamics, distribution, abundance, intensity and feeding behavior [5]. Intensity of change in climatic ecosystem noted by meteorological science has showed a direct and indirect affect on the prey and host relationship, their immune responses and rate of development, their fecundity and various physiological functions [64, 65, 5]. Studies conducted during 2008-2012 on various factors including anthropogenic, biotic and a-biotic were assume to be the responsible of Asian Longhorn Beetle distribution [52, 10]. A-biotic disturbances particularly upper and lower thermal affects check the insect multiplication, diapauses, emergence, flight and the dispersal rate [64, 65]. Not only high temperature thresh hold is responsible for these variation but cool temperature play an important role in intrinsic properties of insect species [46]. For instance, insects facing to cooled stress will possess dark body color as compare to those living in hot climate. In addition to a-biotic factors, biotic changes are also equally responsible for the physiological, behavioral and morphological adaptations in the insects along with its population fluctuation [44, 31]. Among biotic stresses of agro-ecosystem, terrestrial flora played most vital role in the development of various stages of terrestrial insects, their oviposition and hatching success. On the plants different insects feed like pollinator and other herbivorous. Plants showed various responses against different insect pests. Certain bivore induce plant volatile influence the carnivorous insects to attack on folivorous species [11, 36]. In this study strong effect of florivory and folivory were significantly affected due to emission of HIPVs contrary to the pollinator visitation [36].

2. A-biotic factors

Anthropogenic and natural environmental variations are voraciously affecting the arthropods with the passage of time. Certain factors like thermal affect is changing the status of pest by suppressing or stimulating genetic potential, rate of fecundity and mortality and range of hosts [21, 46]. Variable wavelength of white light specifically for red and far red light when absorbed by photosynthetic system as an unambiguous signal of proximity of hearers causing a good developmental responses like shade avoidance responses [49]. Survival rate of young ones of *Cnaphalocrosis medinalis* (Rice leaf folder) was affected at 35 °C even adults emerging from these pupae could not laid eggs. In some biological control agents particularly *C. lividipennis* (egg predator) showed a positive response to predation and decrease the handling time [28].

2.1 Insects Responses to High Temperature

In multi climatic factors particularly temperature can extend or reduce the life cycle of insects [46]. High thermal thresh hold influence the insects cycle stage, growth or some internal metabolic activities. For example in case of *Helicoverpa armigera* egg period was observed 7.9 days at 28 °C but extended 10.4 days at 25 °C. Degree days for hatching are negatively correlated with rise in temperature from 10-27 °C. Generation time of *L. acuta* was supposed to be increased 1-3 days with the raise to 3 °C [28, 27]. In costal environment fitness and survival of terrestrial insects was greatly affected due to a-biotic factors especially in case of soil salinity. In the case study of rice insect pests under influence of global warming and meteorological factors was analyzed in Korea in 1992-2008. Experiment was conducted on eight regions classifying the samples into clustures (I, II, III, IV). The first two and last two clusters were collected before 2000, respectively. Population of *S. lurida* was less two clusters (I, II) as compared to *L. oryzophilus* having high density in cluster III and IV [33]. In another case study of European forest including herbivore insects against climatic change like global warming. Ectothermic organisms had a great response against dispersal, fecundity, mortality, reproduction or multiplication and resistance through community interactions. *Thaumetopoea Pityocampa* was monitored had a great effect on altitudinal and latitudinal dispersion intensity checked by thermal effect or global warming modification [40]. Population dynamic of biological control agent is also affected due to thermal effect or drought conditions. Eggs of Asian lady beetle (*Harmonia axyridis*) were placed under stress or 41, 39, 37 °C and control (25 °C) in ascending order respectively. These eggs were exposed for 1 hour then shifting to normal condition (25 °C) up to their hatching. Larvae were not emerged in the eggs which are exposed to 41 °C. While for weight, survival, longevity, development and reproduction of Asian lady beetle exhibited significant differences against thermal effect. Overall reproduction, oviposition period and longevity of insect were reduced while pre-oviposition period was positively affected to increase in temperature [44; 66; 21]. The response of insects varies against a series of temperatures as 9-55 °C enhancing individual insect mortality. Insects flourish up to 10 °C but below 6 °C mortality of certain insects like coleopterons species goes up to > 99 °C after 9 months at 45% R.H. storage conditions. Many psocopteran and coleopterons species were dead almost 99% at 50 °C within 2.5 h [7]. Some sucking insects like blood sucking bug (*Rhodnius prolixus*) when use their proboscis for feeding they extend it. This proboscis action response (PER) varies due to the temperature of an object itself or thermal effect in the environment. In *Rhodnius prolixus* triggering response of PER was highest at 30 and 35 °C where temperature of thermal background was below 35 °C. It was concluded that bugs prefers optimal temperatures as present in most of the mammal for maximum proboscis extention response [23]. In case of insect pest management population fluctuation, various physiological process and different environmental temperatures showed a significant linkage. When two flies which medfly (*Ceratitis capitata*) and natal fruit fly (*C. crosa*) was exposed to radiation expressing as sensitive to temperature used in the sterile insect technique. In the field experiments these mutated species showed greater longevity under as compared to others, so helpful in male sterile insect technique [43]. Tropical species of insects considered to be the high risk of microclimatic variation and behavioral optimization than the temperate regions. Ants (*Iridomyrmex purpureus*) forage for short period of time even when soil temperature is 45.8±1.3 higher than their thermal limit. Ants could not elevate higher thermal effect tolerance utilizing plastic responses [42].

2.2 Insect Responses Low Temperature

Cooling and freezing have a great effect to disturb the physiological, mechanical and behavioral of the various insects [44, 31]. It can change the chemical ingredients and causing dehydration of the cells or maintaining body fluids keeping liquids below melting point [53]. In scientific literature considerable research has been made to check the physiological behavioral response of insect against a-biotic factors [53]. In this regard experiment was performed to check out the thermal effect on reproduction, development and survival rate of insects. They noted that insects could not bear the challenge against high and low thresh hold temperatures. High mortality was observed and somewhat developmental rate was affected. They also performed the successful insect modeling that can aid to analyze the insect population response and behavior against climatic change [31; 46]. In some beetles (*Alphitobius diaperinus*) bear oxidative damage against cooled thermal stress but antioxidant system is switch on to recover this cooled induce damage [34]. Life cycle gene expression of yellow meal worm beetle was (*Tenebrio molitor*) observed under constant (18±1 °C) and variable temperatures (mean=18 °C and variance of 6.8 °C). Insects were more cool tolerant against variable thermal affect with maximum gene expression (*Hsp70*) [3]. In various insects species fecundity and survival enhance due to fluctuating regimes (FTR) contain cycles between both benign and stressful low temperatures. Results also revealed that at larval stage body water (BWCo) and lipids (BLC) do not change with reaction FTR and show long term fitness consequences [9]. Pine beetle flourish and disperse with better survival rate at warm winter as compared to lethal (-16 °C) which reduce drastically. Aphids can produce 1-5 generation more with an increase a 2ºC in a temperature. In response to minute change in temperature also affect the pre-oviposition period, oviposition and survival of insects is strongly affected. *Nilapavata lugens* (Brown plant hopper) showed no affect on survival ability between 25-35 °C but reduced at 40 °C. In a similar way female oviposited in higher rate at 35 and 40 ºC as compared to 25 and 30 °C. In contrast to survival and oviposition, pre-oviposition period was decreased at high temperatures [64]. It was observed that *N. cincticeps* population fluctuate from 3-4 with change in thermal effect. Both of *N. cincticeps* and *C. suppressalis* greatly affect to global warming. Their population boost up due to winter temperature, significantly can be related the number of generation per year. In winter season death rate of adults of *Nezara viridula* and *Halyomorpha halys* was supposed to be decreased 15% by each increase of 1 °C temperature. On the other hand number of generation per year of *C. suppressalis* decrease after 2 °C warming. Degree day variation in sucking insect (mustard aphid) can alter its infestation. In a similar way in *Leptocorisa acuta* (rice ear head bug) increase or decrease in population is affected with each raise of 3 °C [47].

2.3 Humidity Influences on Insect Fauna

Various insects respond to a-biotic factors like humidity, thermal affect, light and food etc. in different ways. These a-biotic factors not only affect the behavior of insects but also disturb the physiological mechanism [44; 31]. When variation in a-biotic environment likes humidity, heat light and diet give a stress to host in return the host produce immune responses. Immune responses can be severe against the insecticidal effect or chloric restriction or starvation in case of diet factors. In physical environment major factors (temperature, light, humidity etc.) can be assessed by observation of the rate of change rather than describing direct change in a specific physiological reaction [22, 44, 31]. These factors can the mortality, fecundity, generation time, multiplication rate, sex ratio and somewhat mutation. For instance, with the range of temperature speed of development can be enhance but production of deformities and larval mortality will also increased [15]. Species richness and insect activity varies due to temperature and water availability. Certain receptors like thermo trp's may act as primary integers, source of sensory information (such as environmental moisture and temperatures) which react to a wide range of stimuli. Sub elytra chamber and cuticular hydrocarbons in integument also play a vital role in water conservation and prevention during drought environmental conditions [15].

3. Immune genetic responses

Environmental stress modifies the immune system by stimulating the neurohormone or stress hormone in some insects like mollusks and crustaceans. Immune suppressive changes have been observed with the change in internal environment of these invertebrate [2; 1]. Insects minimize the environmental stress by using malpigian tubules functioning as a central key for surviaval [19]. Activity of melanization, lysozyme level and phenoloxidase (PO) are the immune trait that disturb against diet response i.e. level of carbohydrate affect the activity of phenoloxidase [54, 55].The immune parameters along with activity of phenoloxidase and anti bacteria were strong due to affect of temperature at 30 °C than 10 or 20 °C. Standard metabolic rate was not different between immune treatments. Conclusively energetic cost of immunity as well as immune response was significantly affected by environmental temperature [55, 13]. Thermal relationship was studied against mosquitoes at 18 or 26 °C. Metabolic rate temperature relationship (MR-T) was significantly influence against adult treatments. The aquatic larval stage showed phenotypic plasticity against thermal effect [2; 25]. Ovarian dynamics and reproductive plasticity in butterfly (*Pararge aegeria*) is affected due to both multiple intrinsic (body mass and age) and extrinsic (temperature and flight) environmental variables. Thermal effect enhance overion dynamic than flight. Flight can affect egg mass due to changing in water contents [55, 24]. Rise in temperature increase in respiration and metabolism of insects. Deviation from upper and lower limits from critical thermal points also affect endocrine and nervous system, influencing development, bahavioural change and elicitation of different heat shock proteins [44, 2, 41].

4. Gaseous effect

Insects showed different responses against different concentrations of the gases. Maximum or minimum level of the gases like oxygen and carbon dioxide may cause hypoxia or hyperoxia like conditions. In terrestrial insects for example *S. Americana*, *D. malenogaster*, *T. moliteor*, *C. vomitoria*, *M. sexta*, *C. trichopterous* and *Manduca* species etc. showed different responses against hypoxia and hyperoxia. Most of them produce compensatory changes in ventilation and opening of spiricles when exposed to hypoxia or hyperoxia for short period of time. In case of its severity enhance oxidative stress and reduce their survival but moderate stress boost up the development time and the size of the body in most of the insect species by some unknown reactions [27]. In laboratory experiment when exhaust gas (N) affect on *Piceaabies* (Spruce seedlings) was checked out at ditrophic level. The exhaust gas did not play role in nitrogen metabolism or defense chemical production but exposed seedling were greatly affected. In a similar way there was not significant affect on spruce shoot aphid (*Cinara pilicornis*) performance in shoot elongation [61]. High mortality in crickets was observed due to high fat diet when infection was induce to anorexia [14]. Population dynamic of herbivore insects is not only affected by multi factor climatic change but also check out their performance. When three major variants like carbon dioxide, warming and drought were separately manipulated in a Danish health land ecosystem. It was observed under ambient conditions the weight and survival of the larvae (*Lochmaea suturalis*) was normal but decreased significantly with the change of above mentioned factors. Their (carbon dioxide, warming and drought) individual affects was not so effective but showed high response when these factors were combined applied. So, insect herbivores response was high against above three factors [51]. Under variable temperatures (15-35 °C) and concentration of oxygen (10, 21 and 40%) metabolic rate differs in puparia of *Glossina pallidipes.* Dominant effect was observed due to thermal effect on metabolic rate of puparia but in case of oxygen little significant effect was noted [6].

5. Response to chemical

In pesticide era especially in 1914 plenty of resurgent pests were nominated along with residual effects in food that cause human health hazards. Insect responds to chemicals as various genetic, morphological and physiological resistances. Against DDT *Musca domestica* change their active sites in the body. *Merzobus soledadinus* (Ground beetle) was native to South America but slowly spread in the riparian zones and forests where salinity level was not high. Experiment was performed to check the response of beetles against different salinity levels i.e. 0%, 35%, 70% at 4 and 8 °C. Results showed a massive body water contents was lost when exposed to high salinity levels 35 and 70% as compare to controls. Production of some metabolic solutes like alanine, glycine, proline and arythritol accumulation was also reported in case of enhancing their survival ability [29]. Some insects also change their behavior of egg laying on sprayed plant. *Bombyx mori* respond interestingly as measuring the chemical signal in contrast to flies that can only sense them while feeding. Many insects produce the cross resistant behavior against plenty of various insecticide groups like white fly, American boll worm etc.[48]. Use of chemical control is reported about 4000 years ago. Up to know the blind use of chemicals and their residues in the environment has changed the insect response and behavior by morphologically, physiologically and genetically. Insect escapes when a chemical is present in their territory range [48]. Another active ingredient known as DEET (*N*, *N*-diethyl-m-toluamide) have strong repellent effect against household insects. Its concentration in the environment range from 40-3000 ng L^{-1} present in ground water, drinking water, treated effluent and streams has been reported around all over the world [17; 55; 48].

6. Pollutants disturbing arthropods

Phytophagous insects varied respond in reduction of pupal weight, increase in growth rate, larval mortality and accumulation of heavy metals like nickel, cadmium, zinc and copper. While consuming these heavy metals on their infested plants [38]. Elevation in immune responses or arthropods is in a result of high rate of population [35; 62]. Increase in organic and inorganic pollutants disturb the terrestrial ecosystem particularly insects among arthropods. Plenty of pollutants involved in insect population dynamic like carbon oxides, sulfur oxide, nitrogen oxide, acidic rain and acidic fogs. Due to the affect of pollutants tri-trophic interaction (plant herbivores and natural enemies) are severely disturbed [62]. Insect population fluctuations particularly herbivorous insects can be checked by pollutants affecting. In the study of these 203 insects herbivore fitness components and population patterns were analyzed against pollutants environment. Highest fitness results were calculated (75.4%) in response to bottom-up (host plant quality) factors. On the other hand a few contribution (9.9%) fitness significant affect was observed due to top-down factors (natural enemies) [12]. Larval growth and immune responses of *Epirrita autumnata* (Geometrid moth) were checked against heavy metal polluted environment. RGR (Relative growth rate) and pupal weight were lower in polluted trees as compare to control. On the other hand immune responses of the emerged moth were lower in the control as compare to the polluted trees [60].

7. Biotic factors

7.1 Effect of Landscaping in Trophic environmental interaction

Population fluctuation also depends upon the vegetative biodiversity and intensity. Insects feeding and multiplication was higher on extensively grazed pasture. Insect diversity boost up against vegetative patterns was in an order intensively grazed < extensively grazed. On the other hand recolonization of insects was more in short term ungrazed as compared to long term ungrazed pasture but relationship of prey and its predator remained unaffected against grazing intensity [32]. In vertebrate density enhance due to complex habitat like grassy habitat greatly supports the predatory [30]. Landscape pattern and diversity also influence the landing of flying insects. Sometimes vegetative medium attract or rejects the aerial insect stock no doubt somewhat related to their landing behavior. Wheat crop proved very crucial to observe the rate of landing of some aerial insects as studied in Brittany region in western France. Multi scale model was developed for aerial insect flights can be used as a management tool [16].

7.2 Host plant responses

In Trophic environment modification and adaptation in plants like anti-xenosis and anti-biosis check out the insect population fluctuations. Respiration rate and body temperature of the herbivore insect feeding on plant has shown significant effect against modification of leaf transmittance. Physically feed backs of herbivore insects showed variations in metabolic rate due to different nutritional modifications [45; 11]. In California it was studied that by the harbor of various insect pests their predator or parasitoid efficiency was higher in case of cover crops. Different hypothesis were tested as 1).This universe never is green permanently. 2).Every green thing is edible. 3).All edible things have not high quality to support the herbivore population [18]. Habitat of arthropods like insects has a vital role in the fluctuation of their population. Particularly, response of a niche in conservatism is present but not common. Some evolutionary combination has a limited significance for predicting species responses in field environment [8]. In case of ovarian oosorption, seasonally challenging environmental adaptations were also found to be effective in resident females as compare to migrants [4].In combination of host plants and prey influencing the behavior and feeding response of *Cryptolaemus montrouzieri* (Mealy bug destroyer, Coccinelid beetle) was significantly checked. Beetles were released as bio-control agent in orchard trees and the pest species. In their response oviposition rate of the mealy bug destroyer was reduced. Beetle greatly response in olfactometer trial against native mealy bug as compared to other species but strongly avoided to citrus species [21]. In insects, weed system nutrients play a vital role in population dynamics. Nutrients variable had a great affect on insect and its population for example it can increase their herbivory, engaulfing extra food, changing their food material, or medium a host or can force them to migrate in a new flora. In a similar way experiment was performed in South Africa on *E. crassipes* plants providing same level of nutrients against *C. aquatucum* herbivory showing great affect on plant growth and its productivity [11]. Weed fauna also play very important role in insect population dynamic as giving positive or negative responses. It can serve as a habitat or prey culture or traps of biological control agents supporting its population. In cowpea crops having weeds multiply the *Empoasca species* and *Aphis craccivora.* In weed free field, insect population was also found two fold due to the absence and reduction in natural enemies [58]. In a study of some dipterous and coleopterons insect density or damage was observed due to surrounding environment including habitat of winter oil seed rape. *Psylliodes chrysocephala* and *Delia radicum* were found to be highly attacking due to sowing date. In early sowing favors the *Delia radicum* damage with little damage of *P. chrysocephala.* In case of plant density retards the attack of these insects. Against *Psylliodes chrysocephala* (Cabbage stem fly) had a significant nitrogen availability and plant vigor. Surrounding habitat and vegetative environment was approved to have a great effect on insect occurrence and their abundance [59]. Human involvement, change in flora, arrival of new pest from other continents and climatic factors etc or the drivers to check the insect population dynamic. Decrease in insect species was observed on coniferous trees. In Netherland 18 species were observed throughout the 61 year out of 77 species [39]. Both in natural and agro-ecosystem diversity and abundance of insets can positively correlated with phyto-diversity. Natural structural complexity plant productivity or nutrition can be source of their population dynamics. In previous years (2000 and 2001) population dynamic was significantly correlated with the irrigation treatments [63]. During crop protection strategies in agro ecosystem of agriculture pollen beetle population showed variable response in eight spatial scales in 42 fields of oil seed crop (Rape). Low damage was observed in plants having high nitrogen but on the other hand high proportion of population was observed in woodland at large landscape. In multi scale approach concluded that complexity of landscape determines the population of pollen beetle [50, 11].

7.3 Crowding Effect

The idea of competition can also be formulize into the concept of crowding but competition may be inter or intra-species. Response of crowding for an individual and whole insect population can be positive and negative [37]. It modifies its rate, for instance, increase in population density may decrease their rate of increase. In case of social insects queen boost up egg laying but in over population its efficiency may lose down. Another best example of crowding is *Tribolium castaneum* in which density dependent effect is positively correlated with the adult emergence on the floor surface. Secretion of ethylquinoneand its medium contamination forces the adult beetle to come on its surface. Due to crowding competition in ovipostion sites in beetles is enhance ultimately, lowering the oviposition rate. Similar type of effect was observed in other storage pest like *Tribolium confusum.* Where egg laying was stopped without medium and modifying the genital organ. On the other hand in case of *Sitotroga cerealella* burst egg laying take place due to constant production in the ovaries. In *Callosobruchus chinensis* increase in density dependent factors eggs can be laid on occupied beans enhancing their larval competition. Similar kind of competition was recorded in *Trichogramma* parasitizing the eggs of *Sitotroga cerealella*. High density of larvae of *drosophila* suppresses the further adult oviposition. To manage the crowding factors in some insects adopted the canabolism like first larval instar of *Helicoverpa species* [56, 20]. In a study four different hypothesis were tested against insect population dynamics that: remove of the niches of the insects also bounce up the its population density causing insects crowding in the remaining habitat[46]. A landscape which has high number of small patches must have high population density [48]. The inter-spatches distance of fragmentation in a landscape must have a positive effect on an insect population density (3). Above two hypotheses can lose their effectiveness with the passage of time after removal of habitat [7]. The conclusion do not strengthened the first hypothesis. Using the four Coccinellid species, second and third hypothesis successfully positively approved. Resultantly fragmentation enhances the immigration flow to patches aggregately increasing population density [26; 37]. Insects are the most successful organisms present in almost on every vegetative world. To fight for food and shelter they migrate from one crop to another crop, one cropping system to another cropping systems or one climatic environment to another totally different climatic conditions. CLIMAX model is used to check the response of invasive species which is migrated to the new climatic conditions. To analyze the pest risk a generic expert system which is name as PESKY can be helpful to check their response against an unknown environment [20, 57].

8. Conclusion

Every organism particularly insects in arthropods respond to every deviation from normal environmental conditions. Against high or low thermal thresh hold or fluctuating humidity and varied wavelength of light stimulate the inset to respond in a plenty of way. It can affect their ovulation, rate of fecundity, development, survival, multiplication and various immune and genetic responses. In biotic stresses certain plant characters (anti-xenosis, anti-biosis), nutritional modifications, variation in flora (landscape diversity, cover crops) and insect crowding influence insect multiplication, emergence and migration.

9. Acknowledgement

We are thankful to Dr. Abu Bakar M. Raza (Assistant Professor) and Dr. M. Asam (Assistant Professor) who helped us for reading and evaluation of this review research.

10. References

1. Adamo SA. The effects of the stress response on immune function in invertebrates: An evolutionary perspective on an ancient connection. Hormones and Behavior 2012; 62(3):324-330.
2. Adamo SA, Lovett MME. Some like it hot: the effects of climate change on reproduction, immune function and disease resistance in the cricket *Gryllus texensis*. The Journal of Experimental Biology 2011; 214:1997-2004.
3. Arias MB, Poupin MJ, Lardies MA. Plasticity of life-cycle, physiological thermal traits and Hsp70 gene expression in an insect along the ontogeny: Effect of temperature variability. Journal of Thermal Biology 2011; 36:355-362.
4. Attisano A, Tregenza T, Moore AJ, Moore PJ. Oosorption and migratory strategy of the milkweed bug, *Oncopeltus fasciatus*. Animal Behaviour 2013; 86(3):651-657.
5. Ayres JS, Schneider DS. The role of anorexia in resistance and tolerance to infections in Drosophila. PLoS Biol 2009; 7:1000-1005.
6. Basson CH, Terblanche JS. Metabolic responses of *Glossina pallidipes* (Diptera: Glossinidae) puparia exposed to oxygen and temperature variation: Implications for population dynamics and subterranean life. Journal of Insect Physiology 2010; 56(12):1789-1797.
7. Beckett SJ. Insect and mite control by manipulating temperature and moisture before and during chemical-free storage. Journal of Stored Products Research 2011; 47(4):284-292.
8. Bennett JA, Cahill JF. Conservatism of responses to environmental change is rare under natural conditions in a native grassland. Perspectives in Plant Ecology, Evolution and Systematics 2013; 15:328-337.
9. Boardman L, Sørensen JG, & Terblanche JS. Physiological responses to fluctuating thermal and hydration regimes in the chill susceptible insect, *Thaumatotibia leucotreta*. Journal of Insect Physiology 2013; 59(8):781-794.
10. Bone NJ, Thomson LJ, Ridland PM, Cole P, Hoffmann AA. Cover crops in Victorian apple orchards: Effects on production, natural enemies and pests across a season. Crop Protection 2009; 28(8):675-683.
11. Bownes A, Hill MP, Byrne MJ. The role of nutrients in the responses of water hyacinth, *Eichhornia crassipes* (Pontederiaceae) to herbivory by a grasshopper *Cornops aquaticum* Brüner (Orthoptera: Acrididae). Biological Control 2013; 67(3):555-562.
12. Butler CD, Trumble JT. Effects of pollutants on bottom-up and top-down processes in insecteplant interactions. Environmental Pollution 2008; 156:1-10.
13. Catalán TP, Wozniak A, Niemeyer HM, Kalergis AM, Bozinovic F. Interplay between thermal and immune ecology: Effect of environmental temperature on insect immune response and energetic costs after an immune challenge. Journal of Insect Physiology 2012; 58(3):310-317.
14. Chambers MC, Schneider DS. Pioneering immunology: insect style. Current Opinion in Immunology 2012; 24(1):10-14.
15. Chown SL, Sørensen JG, Terblanche JS. Water loss in insects: An environmental change perspective. Journal of Insect Physiology 2011; 57(8):1070-1084.
16. Ciss M, Parisey N, Dedryver CA, Pierre JS. Understanding flying insect dispersion: Multiscale analyses of fragmented landscapes. Ecological Informatics 2013; 14:59-63.
17. Costanzo SD, Watkinson AJ, Murby EJ, Kolpin DW, Sandstrom MW. Is there a risk associated with the insect repellent DEET (N, N-diethyl-m-toluamide) commonly found in aquatic environments?. Science of the Total Environment 2007; 384:214-220.
18. Crawley MJ. Insect herbivores and plant population dynamics. Ann Rev Enlomol 1989; 34:531-564.
19. Davies SA, Overend G, Sebastian S, Cundall M, Cabrero P, Dow JAT, *et al*. Immune and stress response ‘cross-talk’ in the Drosophila Malpighian tubule. Journal of Insect Physiology 2012; 58:488-497.

20. Dick J. Stress responses in insect colonies. Ann Appl Biol 1937; 24:762-765.
21. Finlay-Doney M, Walter GH. Behavioral responses to specific prey and host plant species by a generalist predatory coccinellid (*Cryptolaemus montrouzieri* Mulsant). Biological Control 2012; 63(3):270-278.
22. Fränzle O. Chapter 2 Bioindicators and environmental stress assessment. In A. M. B. B.A. Markert & H. G. Zechmeister (Eds.), Volume 6, Trace Metals and other Contaminants in the Environment, Elsevier, 2003, 41-84.
23. Fresquet N, Lazzari CR. Response to heat in *Rhodnius prolixus*: The role of the thermal background. Journal of Insect Physiology 2011; 57(10):1446-1449.
24. Gibbs M, Van Dyck H, Karlsson B. Reproductive plasticity, ovarian dynamics and maternal effects in response to temperature and flight in Pararge aegeria. Journal of Insect Physiology 2010; 56(9):1275-1283.
25. Gray EM. Thermal acclimation in a complex life cycle: The effects of larval and adult thermal conditions on metabolic rate and heat resistance in *Culex pipiens* (Diptera: Culicidae). Journal of Insect Physiology 2013; 59(10):1001-1007.
26. Grez A, Zaviezo T, Tischendorf L, Fahrig L. A transient, positive effect of habitat fragmentation on insect population densities. Oecologia 2004; 141:444-451.
27. Harrison J, Frazier MR, Henry JR, Kaiser A, Klok CJ, Rascón B. Responses of terrestrial insects to hypoxia or hyperoxia. Respiratory Physiology & Neurobiology 2006; 154(1–2):4-17.
28. Heong KL, Song YH, Pimsamarn S, Zhang R, Bae SD. Global Warming and Rice Arthropod Communities: Springer publications Berlin, 1995.
29. Hidalgo K, Laparie M, Bical R, Larvor V, Bouchereau A, Siaussat D, *et al*. Metabolic fingerprinting of the responses to salinity in the invasive ground beetle *Merizodus soledadinus* at the Kerguelen Islands. Journal of Insect Physiology 2013; 59(1):91-100.
30. Holland JM, Storkey J, Lutman PJW, Birkett TC, Simper J, Aebischer NJ. Utilisation of agri-environment scheme habitats to enhance invertebrate ecosystem service providers. Agriculture, Ecosystems & Environment 2014; 183(0):103-109.
31. Karl I, Stoks R, De Block M, Janowitz SA, Fischer K. Temperature extremes and butterfly fitness conflicting evidence from life history and immune function. Glob Change Biol 2011; 17: 676-687.
32. Kruess A, Tscharntke T. Contrasting responses of plant and insect diversity to variation in grazing intensity. Biological Conservation 2002; 106(3):293-302.
33. Kwon Y-S, Chung N, Bae M-J, Li F, Chon T-S, Park Y-S. Effects of meteorological factors and global warming on rice insect pests in Korea. Journal of Asia-Pacific Entomology 2012; 15(3):507-515.
34. Lalouette L, Williams CM, Hervant F, Sinclair BJ, Renault D. Metabolic rate and oxidative stress in insects exposed to low temperature thermal fluctuations. Comparative Biochemistry and Physiology 2011; 158(Part A):229-234.
35. Larsson S. Stressful times for the plant stressdinsect performance hypothesis. Oikos 1989; 56:277-283.
36. Lucas-Barbosa D, van Loon JJA, Dicke M. The effects of herbivore-induced plant volatiles on interactions between plants and flower-visiting insects. Phytochemistry 2011; 72(13):1647-1654.
37. M. DD, D. HR. A survey and overview of habitat fragmentation experiments. Conserv Biol 2000; 14:342-355.
38. McEnroe NA, Helmisaari HS. Decomposition of coniferous forest litter along a heavy metal pollution gradient, south-west Finland. Environmental Pollution 2001; 113:11-18.
39. Moraal LG, Jagers op Akkerhuis GAJM. Changing patterns in insect pests on trees in The Netherlands since 1946 in relation to human induced habitat changes and climate factors—An analysis of historical data. Forest Ecology and Management 2011; 261(1):50-61.
40. Netherer S, Schopf A. Potential effects of climate change on insect herbivores in European forests—General aspects and the pine processionary moth as specific example. Forest Ecology and Management 2010; 259(4):831-838.
41. Neven LG. Physiological responses of insects to heat. Postharvest Biology and Technology (2000); 21(1):103-111.
42. Nigel RA, Hart RA, Jung M, Hemmings Z, Terblanche JS. Can temperate insects take the heat? A case study of the physiological and behavioural responses in a common ant, *Iridomyrmex purpureus* (Formicidae), with potential climate change. Journal of Insect Physiology 2013; 59:870-880.
43. Nyamukondiwa C, Weldon CW, Chown SL, le Roux PC, Terblanche JS. Thermal biology, population fluctuations and implications of temperature extremes for the management of two globally significant insect pests. Journal of Insect Physiology 2013; 59(12):1199-1211.
44. Overgaard J, Sorenson JG. Rapid thermal adaptation during field temperature variations in *Drosophila melanogaster*. Cryobiology 2008; 56:159-162.
45. Pincebourde S, Casas J. Leaf miner-induced changes in leaf transmittance cause variations in insect respiration rates. Journal of Insect Physiology 2006; 52(2): 194-201.
46. Régnière J, Powell J, Bentz B, Nealis V. Effects of temperature on development, survival and reproduction of insects: Experimental design, data analysis and modelling. Journal of Insect Physiology 2012; 58(5):634-647.
47. Reji G, Chander S. A degree-day simulation model for the population dynamics of the rice bug, *Leptocorisa acuta* (Thunb.). J Appld Entomol 2008; 132:646-653.
48. Rodrigues LAD, Varriale MC, Godoy WAC, Mistro DC. Spatiotemporal dynamics of an insect population in response to chemical substances. Ecological Complexity 2013; 16(0):51-58.
49. Ruberti I, Sessa G, Ciolfi A, Possenti M, Carabelli M, Morelli G. Plant adaptation to dynamically changing environment: The shade avoidance response. Biotechnology Advances 2012; 30(5):1047-1058.
50. Rusch A, Valantin-Morison M, Sarthou JP, Roger-Estrade J. Effect of crop management and landscape context on insect pest populations and crop damage. Agriculture, Ecosystems & Environment 2013; 166(0):118-125.
51. Scherber C, Gladbach DJ, Stevnbak K, Karsten RJ, Schmidt IK, Michelsen A, *et al*. Multi-factor climate change effects on insect herbivore performance. Ecology and Evolution 2013: 1-12.
52. Shatz AJ, Rogan J, Sangermano F, Ogneva-Himmelberger Y, & Chen H. Characterizing the potential distribution of the invasive Asian longhorned beetle (*Anoplophora glabripennis*) in Worcester County, Massachusetts. Applied Geography 2013; 45(0):259-268.

53. Sinclair BJ, Vernon P, Jaco Klok C, Chown SL. Insects at low temperatures: an ecological perspective. Trends in Ecology & Evolution 2003; 18(5):257-262.
54. Siva-Jothy MT, Moret Y, Rolff J. Insect immunity: an evolutionary ecology perspective. Advances in Insect Physiology 2005; 32:1-48.
55. Söderhäll K, Cerenius L. Role of the prophenoloxidase-activating system in invertebrate immunity. Current Opinion in Immunology 1998; 10:23-28.
56. Sonleitner FJ. The Stress Factor in Insect Colonies. Bull World Health Organ. 1964; 31(4): 545–549.
57. Sutherst RW. Predicting the survival of immigrant insect pests in new environments. Crop Protection 1991; 10(5):331-333.
58. Takim FO, & Uddin RO. Effect of weed removal on insect populations and yield of Cowpea [*Vigna unguiculata* (L) Walp] Australian Journal of Agricultural Engineering 2010; 1(5):194-199.
59. Valantin-Morison M, Meynard JM, Doré T. Effects of crop management and surrounding field environment on insect incidence in organic winter oilseed rape (*Brassica napus* L.). Crop Protection 2007; 26(8):1108-1120.
60. Van Ooik T, Rantala MJ, Saloniemi I. Diet-mediated effects of heavy metal pollution on growth and immune response in the geometrid moth *Epirrita autumnata*. Environmental Pollution 2007; 145(1):348-354.
61. Viskari EL, Surakka J, Pasanen P, Mirme A, Kössi S, Ruuskanen J, *et al*. Responses of spruce seedlings (*Picea abies*) to exhaust gas under laboratory conditions— I plant–insect interactions. Environmental Pollution 2000; 107(1):89-98.
62. Warrington S. Relationship between SO2 dose and growth of the pea aphid, *Acyrthosiphon pisum*, on peas. Environmental Pollution 1987; 43:155-162.
63. Wenninger EJ, Inouye RS. Insect community response to plant diversity and productivity in a sagebrush–steppe ecosystem. Journal of Arid Environments 2008; 72(1):24-33.
64. Yamamura K, Kiritani K. A simple method to estimate the potential increase in the number of generations under global warming in temperate zones. Appld Entomol Zool 1998; 33:289-298.
65. Yumamura K, Yokazawa M, Nishimori M, Ueda Y, Yokosuka T. How to analyse long- term insect population dynamics under climate change: 50 year data of three insect pests in paddy fields. Popln ulation Ecol 2006; 48:38-48.
66. Zhang S, Cao Z, Wang Q, Zhang F, Liu T-X. Exposing eggs to high temperatures affects the development, survival and reproduction of *Harmonia axyridis*. Journal of Thermal Biology 2014; 39(0):40-44.