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Aftermath of climate change on insect migration: A review

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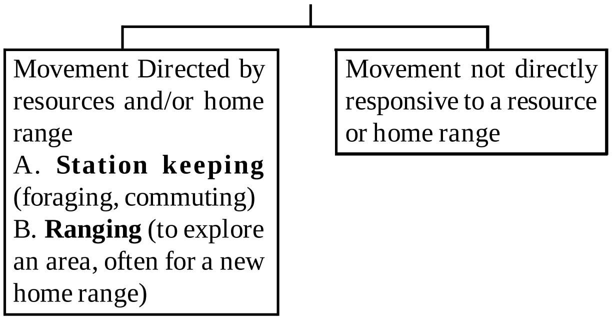
ABSTRACT

Climate change is inflicting a huge impact in all the corners of biosphere. The insects, one of the early inhabitants of the biosphere are well known for their co-evolution with the plants and adaptation to the diverse environments. The power of flight makes the insect community to occupy new habitats and hence insect migration is one of the predominant areas for investigation in the perspective of climate change. The insect migration is a complex science that involves thorough understanding of insect bio-ecology along with knowledge of meteorology, aerodynamics, remote sensing and climatology. The various abiotic parameters that influence the insect migration and the effects of these parameters under the changing climatic scenario are discussed in this paper.

Key words: Climate change, Insect migration.

The first record of insect existence came from the Devonian period (i.e. 500 million years ago). The first flying insect was traced to the carboniferous period (i.e. 354 to 295 million years ago). The insects can occupy new habitats and niches where other species cannot occupy by through their unique ability of flight. The flight is used by insects for dispersal and migration from one place to other to accomplish the biological needs such as host finding, mating etc. Migration refers to a continued movement in a more or less definite direction, in which both movement and direction are under the control of the animal concerned (Williams, 1957). Migration refers to transfer of population from place to place by mass flights (Johnson, 1969). Migratory behavior is persistent and straightened-out movement effected by the animal's own locomotory exertions on or by its active embarkation on a vehicle. It depends on some temporary inhibition of station-keeping responses, but promotes their eventual disinhibition and recurrence (Kennedy, 1985). Dispersal is more simply defined as movement that results in an increase in the mean distance between individuals.

Insects are among the groups of organisms which are most like-ly to be affected by climate change because climate has a strong direct influence on their development, reproduction and survival (Bale *et al*., 2002). The fourth annual assessment report of IPCC predicts an average Surface temperature increase from 1.1 to 5.4°C by 2100 (Meehl *et al*., 2007). One of the reasons for this climate change is increase in anthropogenic CO_2 emission. Insects respond quickly to this climate change as they need a particular temperature preferendum to complete its life cycle. Insect has the unique ability to fly and colonize new habitat. Migration is a type of movement displayed by insects, but it differs from all other types because migratory insects (and other migrants as well) are unresponsive to suitable resources. There are two broad categories of movements:



Insects and climate change: Insects are cold-blooded organisms i.e. the temperature of their bodies is approximately the same as that of the environment. Therefore, the external environment influences the insect's key physiological processes very much. Temperature is probably the single most important environmental factor influencing insect behaviour, distribution, development, survival, and reproduction. Insect life stage predictions are most often calculated using accumulated degree days from a base temperature. The effect of temperature on insects largely overwhelms the effects of other environmental factors (Bale *et al.,* 2002). It has been estimated that with a 2°C temperature increase insects might experience one to five additional life cycles per season (Yamamura and Kiritani 1998). Apart from temperature, moisture and CO_2 effects on insects can be potentially important considerations in a global climate change scenario (Coviella and Trumble 1999).

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Deutsch *et al.* (2008) reported that insects especially in tropics are already living in their temperature preferendum. So the global warming will harm them. The insects in temperate countries will be benefitted. He also reported that there will be increased risk of invasion by migrant pest species. There will be changes in the geographical distribution of the insects.

Characteristics of migration

The organism undertaking migration is undistracted and it doesn't respond to food or mates, otherwise so necessary a part of life functions. The primary triggering factor of migration is environmental cues, such as photoperiod, which forecast habitat change rather than being directly responsive to the change itself (usually deterioration in the quality or availability of resources).The migration behaviors for initiation and termination of migration are distinct for each species such as climbing to the top of a bush or tree branch to take off on migratory flights, behavior they show at no other time.

The wind borne migration is extensively studied in the insects belonging to the orders *viz*., Hemiptera, orthoptera and lepidoptera. The potential for wind borne migration is greater for nocturnal insects than the diurnal insects because during night time the wind speed is less, vertical air movement is nil and the planetary bound layer will be stable (Drake and Farrow, 1988).

Meteorological factors that influence migration

Temperature: Temperature influences insect migration to a greater extent especially in the lepidopterans as illustrated by a report from Britain. In Britain there exists a significant positive correlation between the abundance of lepidopterans with the Central England temperatures during the years 1850 to 1962 for months, May to September and November and significantly negatively correlated with January. One of the possible outcomes of global warming is the increase in persistence of migrant species in Britain (Sparks *et al*., 2005 and Sparks *et al*., 2007). There exists a significant correlation between the overall abundance of Lepidoptera between 1864 and 1952 in Britain with the number of migrants for the same period.

The temperatures of more than a century on the migration route of nine migrating butterflies and 20 migrating moths was correlated with the North Atlantic oscillation (NAO) by Sparks *et al.* (2005). They found that increase in temperatures is directly proportional to the number of migrants. They also concluded that, if the global warming continued as predicted in the 21st century, Britain and other northern temperate countries will receive larger numbers of migrant Lepidoptera. The temperature along with wind and rainfall influence the take off of diurnal insects (Riley *et al*., 1995).

The rate of locust egg development is a function of the soil temperature. Eggs can dry up if exposed to wind or can also be destroyed by flooding. Under conditions when soil temperatures are above 35°C, high egg mortality can occur. According to Rubenstein, (1992) the activity of locust is increasing with the temperature in terms of their movement and feeding ultimately resulting in an increase in the fecundity.

Rainfall: Increased precipitation from June to August in some of the gregarization zones of locust in central Sahara would benefit the desert locust (Hulme *et al*., 2001). Migrating insects (desert locust) are adapted to respond to environmental changes, and their subpopulations interlink over distances of thousands of kilometres. The transition from the first instar to the fifth instar requires rainy conditions since the hoppers require vegetation for their survival. The soil moisture in the top soil between 5 to10 cm influences the eggs development.

Relative humidity: Rubenstein, (1992) reported the existence of non-linear relationship between relative humidity and fecundity which result in a dome shaped curve. They also reported that relative humidity influences the locust development and its migration.

Wind direction: Rainey (1977) highlighted that the insects using kinetic energy of atmospheric circulation through downwind movement has enormous survival rate and also they are able to locate and exploit ephemeral vegetation. *Helicoverpa armigera* (Hubner) is a migratory pest in four continents (Fitt, 1989; Riley *et al*., 1992; Vaishampayan and Singh, 1996; Torres-Vila *et al*., 2002). Xu *et al.* (1999) documented long distance migration of *H. armigera* from North to North east China. Migrants flew about 8.5 hours per night. Displacement direction and orientation of the moths are in acute angle to downward wind direction.

The boll weevil was first recorded from Texas in the year 1892 followed by Venezuela in 1949 then Columbia in 1950 followed by Brazil in 1983 from here to Argentina in 1993. A distance of 1400 km is crossed by boll weevil in 23 years. The high wind speeds prevailing during late summer and early fall matching the end of the cotton season favoured the boll weevil to disperse in South America. The highest wind speeds prevailing in Argentina, Brazil and Paraguay are from the north east and north directions and they have a significant influence on boll weevil dispersal from infested areas (Ravelo *et al.,* 2001).

***El nino*:** The *El niño* Southern Oscillation (ENSO) is a global climatic phenomenon characterized by changes in sea surface temperatures. ENSO events have been used to make qualitative forecast for various insect pests, such as rice planthoppers (Zhu *et al*., 1997; Zheng and Liang, 1998), cotton bollworm (Qin *et al*., 2003), *Dendrolimus punctatus*

(Bi *et al*., 2003) and *Locusta migratoria manilensis* (Zhang and Li, 1999).

Aphrissa statira, Lemony yellow Sulphur butterflies a common inhabitant found from Mexico to Brazil. *A. statira* usually migrates across the central Panama from Atlantic rainforests to the Pacific drier forests following the arrival of rain (Srygley and Dudley, 2011). The peak migration occurs a month after the rainy season begins in Panama. The analysis of 16 year data on the migratory behaviour of *A. statira* and 8 year data on its host plant (*Callichlamys latifolia*) reveals that the number of migratory butterflies was greatest in *El Nino* years. The migration is positively correlated with the flushing of *Callichlamys latifolia* its host plant. The adult prefers to oviposit on young green leaves which flush after the rains. Both the host plant's flushing and number of adults emerging from the new leaves were greater during the *El Nino* years (Srygley *et al*., 2009).

Climate change on migration: Climate change is associated with warming, elevated CO_2 and regionally changed precipitation. Climate change is a global challenge for nature conservation as it impacts both species and ecosystems. Weather and seasonal changes continue to have considerable impact on migratory species and their conservation status. These species in many ways are more vulnerable than non-migratory species since they rely on multiple habitats and sites for breeding and feeding, and are exposed to climatic variations during their migration.

Migratory species serve as invaluable indicators of the interdependence and linkages between ecosystems and ecological health. The major challenges of climate change in terms of migratory species include extensive migration and ecosystems reorganization occurring in landscapes that were not as fragmented nor as degraded as those found today. Therefore, the adaptive capacity of migratory species and the ecosystems they rely on may be limited, and underscores the need for managing existing protected areas or other habitats of high biological importance in dynamic ways.

Higher summer temperatures were linked to migration of higher numbers of Lepidoptera. Higher summer temperatures will benefit the Lepidoptera populations in many ways by increasing their flight, thus leading to higher mating success and egg laying and ultimately larger brood development (Warren *et al*., 1986; Porter, 1992). The 1 to 3°C rise in temperature will result in expansion of the European corn borer (*Ostrinia nibilulalis* Hubner) distribution up to 1,220Km northwards (Porter *et al*., 1991). Continuous rainfall and heavy rainfall will be deleterious to Lepidoptera populations. It can depress flight, and result in reduced mating and oviposition. The heavy downpour and cloudiness will result in drowning of larvae, occurrence of epizoonotics in lepidopterous larvae (Dennis, 1993). The elevated CO_2 will result in reduction of 10 to 30 per cent in foliar nitrogen due to an increase in carbon/nitrogen ratio. The herbivore consumption rate will be increased by 20 to 90 per cent as to compensate the reduced nitrogen availability from plants (Kinney *et al*., 1997; Roth and Lindroth 1994, 1995.).

Enhanced arrival date: A European wide data set has been monitoring the aphid migration since the 1960s (Harrington *et al*., 2001). One consistent pattern that has emerged from this is that, for any latitude, over the past 21 years the average advance in phenology has been about 10 days. In other words, the aphid spring migration has been found across Europe to advance by 14 days for every degree Celsius rise in temperature (Harrington *et al*., 2001). Milder winters result in earlier aphid migrations and hence an earlier threat to crops. More rapid development and reproduction, and reduced mortality due to low temperatures were recorded in aphids (Harrington *et al*., 2001). The aphid migration is closely linked with winter temperature. The first record of *M. persicae* advancing by about two weeks for every degree centigrade rise in the mean temperature of January and February. The time that the last winged aphids are caught is also tending to get earlier, so that overall season lengths for aphid flight are little changed.

Sparks *et al*. (2005) reported that red Admiral was arriving earlier in Britain. The date of peak flight for 104 species of the most common Microlepidoptera in the Netherlands (1955–1994) shows a trend towards earlier flight. The trend is strongest in the past two decades (1975–1994) where the date of peak flight has shifted earlier by an average of 11.6 days (Ellis *et al*., 1997). The date of first appearance has advanced for 26 of 35 butterfly species in the United Kingdom (Roy and Sparks 2000), for all 17 species examined in Spain (Stefanescu *et al*., 2003), and for 16 of 23 species in California (Forister and Shapiro 2003). There is considerable variation in both the direction and magnitude of these changes among species (Parmesan, 2006).

Increased susceptibility of plants: As the rate of advance in the planting of spring crops has generally not matched the rate of advance in aphid phenology, aphids are tending to arrive in crops at earlier growth stages, which are usually more susceptible than older plants to damage caused both by removal of sap and by aphid-borne viruses.

Phenological asynchrony: Where life-cycle events are controlled by temperature, they may be expected to occur earlier, and higher temperatures are likely to facilitate extended periods of activity at both ends of the season, subject to constraints that other factors such as day length and drought might impose. Migratory Red Admiral *Vanessa atalanta* has advanced its return flight in the past 2 decades. Stingling nettle *Urtica dioica* the host of red admiral has not advanced its flowering time (Sparks *et al*., 2005). It is quite conceivable that, under the current rapid changes in climate being experienced, synchrony between trophic levels could become decoupled as a result of subtle differences in the impacts of changes on the timing of cues determining the phenology of constituent species (Harrington *et al*., 1999). For example, changes in synchrony may occur between winter moth *Operophtera brumata* larval emergence date and bud burst of its host plant, sitka spruce *Picea sitchensis* (Dewar and Watt, 1992). With a temperature increase of 2 °C bud burst date is not expected to change dramatically, but larval emergence date is likely to advance dramatically, potentially leading to larval emergence dangerously (for the moth) ahead of bud burst. Pest problems may then be reduced. The decoupling of one synchronous trophic interaction may also lead to the development of others. This can occur when a participant of the original interaction is later brought into synchrony with different members of adjacent levels of the local trophic web. Such switches in synchrony allow pre-adapted exploiters immediate access to new hosts, although it may take time for the member of the higher trophic level to evolve the ability (if it has the capacity for such evolution).

Range expansion: Musolin (2007) observed that in Japan, warmer climate led to the northward migration of the green stinkbug (*Nezara viridula*) a major agricultural pest damaging soybean, rice, cotton and many other crops. In 2006–2007, a survey conducted by Tougou *et al*. (2009) on southern green stink bug, *Nezara viridula* (L.) demonstrated that this northern limit had shifted northwards by 85 km (i.e., at a mean rate of 19.0 km per decade) in Japan. January to February temperature in the region was 1.03–1.91 °C higher in 1998–2007 than in 1960–1969. The number of cold days (with the mean temperature below +5 °C) also significantly decreased, while the annual lowest temperature significantly increased. Mean January temperature and number of cold days are the most important factors controlling the northern limit of distribution of *N. viridula*.

Populations of the corn earworm, *Heliothis zea* (Boddie) in the North America might move to higher latitudes/altitudes, leading to greater damage in maize and other crops. An increase of 1 and 3°C in temperature will result in additional generations of European corn borer in nearly all regions where it is currently known to occur (Porter *et al*., 1991). The sachem skipper butterfly expanded its range from northern California in the year 1950s up to Washington by the year 1990. The Temperatures had risen by 2-4°C over the prior half-century. Winter temperatures directly affect the persistence of *Atalopedes campestris* at its northern range edge, and that winter warming was a prerequisite for this butterfly's range expansion. *A. campestris* responded to regional warming by extending its northern range boundary and thereby expanding its range.

Host range expansion: In the case of crops, if growing conditions become suitable they can, of course, be moved by humans. International trade and tourism also offer the opportunity for species to spread. Insects may come into contact with new potential hosts, and these hosts may already be under some stress, for example as a result of drought, and hence less able to defend themselves. This increases the likelihood of host switching. *Helicoverpa armigera* was found to attack mango in Dharwad and adjoining Kittur area, Belgaum District, Karnataka, India Infestation level 30-40 % (Bharati *et al*., 2007). The comma butterfly, *Polygonia c-album, has* expanded its northern range margin northward in Britain by approximately 200 km in the past 60 years. This range expansion has been associated with an apparent change in its preferred larval host plant from *Humulus lupulus (hop)* to include other plant species, especially *Urtica dioica (nettle)* and *Ulmus glabra (wych elm), host plants* utilized in other parts of its European range and by other closely related *Polygonia species* (Braschler and Hill, 2007).

Increased migrants: Out of the 75 species of migratory Lepidoptera which were recorded at Portland between 1982 and 2005 by Sparks *et al*. (2007) revealed that numbers of migratory species were positively related to temperature anomalies averaged over March to July and suggested a 1°C increase in temperature was associated with an additional 14.4 ± 2.4 migrant species. It is anticipated that further climate warming within Europe will increase the numbers of migratory Lepidoptera reaching the UK

Arrival of new insect pests: *H. armigera* is a serious pest in Portugal and Spain especially in crops such as tomato and green house crops. Occasionally it is reported from southern and south-eastern European countries, especially in years with warm summers. Migrant individuals of *H. armigera* were observed in Denmark, Norway, Sweden (Palmqvist, 2001 and 2002), Estonia, Latvia, Slovenia, Czech Republic and Poland (European Commission, 2006) and the Netherlands. During the summer, the range of *H. armigera* in Europe may extend as far as 59ºN in the northern hemisphere. In northern European countries, gravid female moths could establish a small population outside during favourable weather in the summer and autumn and, with climate change, such events are likely to occur more often. A northwards shift in distribution has been witnessed as global warming makes more northerly areas more suitable for colonisation, for example a species of butterfly (summer migrant to Scandinavia) Clouded Yellow *Colias croceus* is now over-wintering in the UK. The first UK record of the Italian alder aphid (*Crypturaphis grassii)* came from the suction trap at Rothamsted (Harrington, 1998) and this species has since then appeared in most of the traps in England. The African plain tiger butterfly (*Danaus chrysippus)* established its first population in southern Spain in 1980 and by the 1990s it had established multiple, large metapopulations (Haeger, 1999).

CONCLUSION

Insects evolved 500 million years before and still now the process of co-evolution of insects with the host and abiotic factors is going on. The rapid climate change also influences the insect evolution and makes its adaptation to climate change an indispensable thing in its evolution as the insect migration largely depends on the abiotic factors such as temperature, relative humidity, wind current and direction slight change in these parameters will alter their migration pattern to a greater extent. Technologies like, monitoring insect pest migration with GIS, forecasting pest outbreaks and modelling will help us to cope up with the changes in insect migration aggravated due to climate change. The insect migration in the pretext of climate change will result in arrival of new insect pest to a new geographical region or earlier onset of existing insect incidence in a country. Thus the insect migration needs to be studied in an extensive manner in the changing climate scenario.

REFERENCES

Bale, J.S., Masters, G.J., Hodkinson, I.D., Awmack, C., Bezemer, T.M., Brown, V.K., Butterfield, J., Buse, A., Coulson, J.C., Farrar, J., Good, J.E.G., Harrington, R., Hartley, S., Jones, T.H., Lindroth, R.L., Press, M.C., Symrnioudis, I., Watt, A.D. and Whittaker, J.B. (2002). Herbivory in global climate change research: direct effect of rising temperature on insect herbivores. *Global Change Biology*. **8:** 1–16.

Bharati, S. M., Gundannavar, K.P., Giiraddi, R.S., Hilli, J.S., Kamanna, B.C. and Budhihal, R.A. (2007). Mango – A new record for *Helicoverpa armigera* (Hubner). *Current Science*. **92:**1033.

Bi, X. L., Xu, Y.X. and Hong, W. (2003). Relationship between the occurrence of *Dendrolimus punctatus* in Fujian and the ENSO events. *Journal of Fujian College of Forestry*. **23:** 44 –47.

Braschler, B. and Hill, J.K. (2007). Role of larval host plants in the climate-driven range expansion of the butterfly *Polygonia c-album*. *Journal of Animal Ecology*. **76:** 415–423.

Coviella, C.E. and J.T. Trumble, 1999. Effects of elevated atmospheric carbon dioxide on insect±plant interactions. *Conservation Biology*. **13:** 700-712.

Dennis R.L.H. (1993): *Butterflies and Climate Change*. Manchester University Press, Manchester. 302 pp.

Deutsch, C.A., Tewksbury, J.J., Huey, R.B., Sheldon, K.S., Ghalambor, C.K., Haak, D.C. and Martin, P.R. (2008). Impacts of climate warming on terrestrial ectotherms across latitude. PNAS.**18:** 6668–6672.

Dewar, R.C. and Watt, A.D. (1992). Predicted changes in the synchrony of larval emergence and budburst under climatic warming. *Oecologia*. **89:** 557–559.

Drake VA, Farrow, R.A. (1988). The influence of atmospheric structure and motions on insect migration. *Annu. Rev. Entomol*. **33:**183–210

Ellis, W.N., Donner, J.H. and Kuchlein, J.H. (1997). Recent shift in phenology of Microlepidoptera, related to climatic change (Lepidoptera). *Entomologische Berichten, Amsterdam*. **57:** 66–72.

European Commission. (2006). Information on Regulated Non-Quarantine Pests. HA/svi D(2006), Brussels, 17 February 2006.

Fitt, G. P. (1989). The ecology of *Heliothis* species in relation to agroecosystems. *Annu. Rev. Entomol*. **34:** 17–52.

Forister, M.L. and Shapiro, A.M. (2003). Climatic trends and advancing spring flight of butterflies in lowland California. *Global Change Biology*. **9:** 1130–1135.

Haeger, J.F. (1999). *Danaus chrysippus* (Linnaeus 1758) en la Península Iberica: migraciones o dinámica de metapo-blaciones? – *Shilap* **27:** 423–430.

Harrington, R. (1998). An aphid new to Britain. *Entomologist's Record*. **110:** 288.

Harrington, R. I. Woiwod, and Sparks, T. (1999). Climate change and trophic interactions, *TREE*. **14:** 146–150.

Harrington, R., Fleming, R.A. and Woiwood, I.P. (2001). Climate change impacts on insect management and conservation in temperate regions: Can they be predicted? *Agric. Forest Entomol*. **3:** 233–240.

Hulme, M., Dougherty, R., Ngara, T., New, M. and Lister, D. (2001). African climate change: 1900–2100. In: Desanker P (ed) Africa and global climate change. CR SPECIAL 8. *Climate Research.* **17:**145-168.

Johnson C.J. (1969). In Migration and dispersal of insects by flight. Methuen and Company Limited, London

Kennedy, J.S. (1985). Migration, behavioural and ecological. In: Rankin, M.A. (ed.) Migration: Mechanisms and adaptive Significance. Contributions in Marine Science Suppl., Vol. 27, Marine Science Institute, University of Texas, Port Arkansas, Texas, pp. 7-26.

Kinney, K.K., Lindroth, R.L., Jung, S.M. and Nordheim, E.V. (1997). Effect of Co_2 and No_3 availability on deciduous tree: phytochemistry and insect performance. *Ecology*. **78:** 215-230.

Meehl G., Stocker, T., Collins, W., Friedlingstein, P., Gaye, A., Solomon, S., Qin, D., Manning, M., Chen, Z. and Marquis, M. (2007). Climate Change, 2007: The Physical Science Basis. Contribution of Working group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA.

Musolin, D.L. (2007). Insects in a warmer world: ecological, physiological and life-history responses of true bugs (Heteroptera) to climate change. *Global Change Biology*. **13:** 1565–1585.

Palmqvist, G. (2001). Intressanta fynd av storfjarilar (Macrolepidoptera) i Sverige 2000. [Remarkable records of Macrolepidoptera in Sweden 2000.] *Entomologisk Tidskrift*. **122 :** 41-55.

Palmqvist, G. (2002). Intressanta fynd av storfjarilar (Macrolepidoptera) i Sverige 2001. [Remarkable records of Macrolepidoptera in Sweden 2001.] *Entomologisk Tidskrift*. **123:** 53-63.

Parmesan, C. (2006). Ecological and evolutionary responses to recent climate change. *Annual Review of Ecology, Evolution and Systematics*. **37:** 637-669.

Porter, J.H., Parry, M.L. and Carter, T.R. (1991). The potential effects of climatic change on agricultural insect pests. *Agricultural and Forest Meteorology*. **57:** 221-240.

Porter, K. (1992). Eggs and egg-laying. In: Dennis, R.L.H. (Ed). 1992. The Ecology of Butterflies in Britain. Oxford University Press. Oxford. pp 46-72.

Qin, S.L., Zhai, B.P., Zhang, X.X., Zhao, Z.G., Jiang, Y.Y., Qu, X.F. (2003). Using advance ENSO indices to forecast outbreaks of *Helicoverpa armigera*. *Acta Ecologica Sinica.* **23:** 1695–1711.

Rainey, R.C. (1977). Rainfall: scarce resource in «opportunity country». *Phil. Trans. R. Soc*. (B), **278 :** 439-455.

Ravelo, A.C., Grilli, M. and Santa, J.A. (2001). Monitoreo del picudo del algodonero mediante utilización de información satelital y terrestre. *In:* Proceedings of the «Cotton in the Southern Cone – Project on Integrated Pest Management of the Cotton Boll Weevil in Argentina, Brazil and Paraguay CFC/ICAC/04», PART 1, 26-28 June 2001, Fortaleza, Brazil, pp. 215-224.

Riley, J.R., Reynolds, D.R., Mukhopadhyay, S., Ghosh, M.R., Sarkar, T.K. (1995). Longdistance migration of aphids and other small insects in northeast India. *Eur. J. Entomol*. **92:**639–53

Riley, J.R., Armes, N.J., Reynolds, D.R. and Smith, A.D. (1992). Nocturnal observations on the emergence and flight behaviour of *Helicoverpa armigera* (Lepidoptera: Noctuidae) in the post-rainy season in central India. *Bull. Entomol. Res*. **82:** 243–256.

Roth, S.K. and Lindroth, R.L. (1994). Effect of Co_2 mediated changes in paper birch and white pine chemistry on gypsy moth performance. *Oecologia*. **98:** 133-138.

Roth, S.K. and Lindroth, R.L. (1995). Elevated atmospheric Co_2: effects on phytochemistry, insect performance and insect-parasitoid interaction. *Global Change Biol*. **1:**173-182.

Roy D.B. and Sparks, T.H. (2000): Phenology of British butterflies and climate change. *Global Change Biology.* **6:** 407-416.

Rubenstein, D.I. (1992). The green house effect and changes in animal behaviour:Effects on social structure and life history strategies. *Yale University*. 180-192 pp.

Sparks T.H., Dennis, R.L.H., Croxton, P.J. and Cade, M. (2007): Increased migration of Lepidoptera linked to climate change. *Eur. J. Entomol*. **104**: 139–143.

Sparks T.H., Roy, D.B. and Dennis, R.L.H. (2005). The influence of temperature on migration of Lepidoptera into Britain. *Global Change Biology.* **11:** 507–514.

Srygley, R.B., Dudley, R., Oliveira, E.G., Aizprua, R., Pelaez, N.Z. and Riveros, A.J. (2009). El Niño and dry season rainfall influence host plant phenology and an annual butterfly migration from Neotropical wet to dry forests. *Global Change Biology*. **16:** 936-945.

Srygley, R.B. and Dudley, R. (2011). Optimal strategies for insects migrating in the flight boundary layer: mechanisms and consequences. *Integrative and Comparative Biology*. **48:**119–133.

Stefanescu, C., Penuelas, J. and Filella, I. (2003). Effects of climatic change on the phenology of butterflies in the northwest Mediterranean Basin. *Global change biology*. **9:** 1494-1506.

Torres-Vila, L. M., Rodr´ýguez-Molina, M.C., Lacasa-Plasencia, A. and Bielza-Lino, P. (2002). Insecticide resistance of *Helicoverpa armigera* to endosulfan, carbamates and organophosphates: The Spanish case. *Crop Protection.* **21:** 1003–1013.

Tougou, D., Musolin, D.L. and Fujisaki, K. (2009). Some like it hot! Rapid climate change promotes changes in distribution ranges of *Nezara viridula* and *Nezara antennata* in Japan. *Entomologia Experimentalis et Applicata*. 130: 249–258. DOI: 10.1111/j.1570-7458.2008.00818.x

Vaishampayan, Jr.S. and Singh, H.N. (1996). Evidences on the migratory nature of *Heliothis armigera* (Hubner) adults collected on light trap at Varanasi. *Indian J. Entomol.* **57:** 224– 232.

Warren M.S., Pollard E. and Bibby T.J. (1986). Annual and long term changes in a population of the wood white butterfly *Leptidea sinapis*. *J. Anim. Ecol.* **55:** 707–720.

Williams, C.B. (1957). Insect migration. *Annu. Rev. Entomol*., **2:** 163-180.

Xu, G., Guo, Y.Y. and Wu, K.M. (1999). Analyses of pollens adhering to cotton bollworm moths (Lepidoptera: Noctuidae). *Sci. Agric. Sinica*. **32:** 63-68.

Yamamura, K. and Kiritani, K. (1998). A simple method to estimate the potential increase in the number of generations under global warming in temperate zones. *Applied Entomology and Zoology*. **33:** 289-298.

Zhang, Z.B. and Li, D.M. (1999). A possible relationship between outbreaks of the oriental migratory locust (*Locusta migratoria manilensis* Meyen) in China and the El Nino episodes. *Ecological Research*. **14:** 267-270.

Zheng, S.Q. and Liang, J.Y. (1998). Analysis on the impact of El Nino on outbreak of rice planthopper in Guangdong Province. *Plant Protection Technology and Extension*. **18:** 3-4.

Zhu, M., Hu, G.W. and Tang, J. (1997). Effect of globe climate abnormality (ENSO phenomena occurrence) on outbreak of rice brown planthopper in China. *Scientia Agricultura Sinica*. **30:**1-5.