Rothamsted Repository Download

A - Papers appearing in refereed journals

Riley, J. R. and Drake, V. A. 2002. Editorial: technologies for insect movement and migration research. *Computers and Electronics in Agriculture.* 35 (2-3), pp. 57-62.

ELSEVIER

Computers and Electronics in Agriculture
35 (2002) 57–62

Computers
and electronics
in agriculture

www.elsevier.com/locate/compag

Editorial

Technologies for insect movement and migration research

Physical-science based and computing technologies present many opportunities for researchers in whole-organism biology, both in the field and the laboratory. The rapid advancement of these technologies, especially with regard to miniaturisation and increasing capability at reduced cost, continually extends the limits of what researchers can achieve with established methods and it also allows novel approaches to be developed. The field of insect movement is one in which the use of electronics, various remote-sensing and imaging techniques and computing is well established and for which some ingenious solutions to the particular challenge of working with small organisms have been invented. A 1-day symposium on Technologies for Movement and Migration Research at the 21st International Congress of Entomology (ICE), held at Iguassu Falls, Brazil, in August 2000 provided an opportunity for a dozen or so such researchers to make contact—in several cases for the first time—and to describe the techniques they have developed. Because the great majority of the research in this field is driven by the imperative of improving the management of agricultural pests, the symposium papers fall directly within the aegis of ‘Computers and Electronics in Agriculture’ and they have therefore been re-worked and brought together for this Special Issue.

Insect movement occurs over a wide range of spatial and temporal scales. Windborne migratory flight typically continues for several hours, a foraging flight has a typical duration of 1 min or so and an escape reaction lasts for no more than a fraction of a second. Technologies for observing movements over the whole of this range are represented here. At the largest scale, wind-assisted migrations of a few hundred kilometres are regularly achieved by insects flying at altitudes of several hundred metres, often at night. Radar provides the only means of observing this phenomenon directly and four of the papers describe recent technical advances in what has become known as ‘radar entomology’. Cheng et al. describe how they have captured and analysed the digitised plan position indicator (PPI) display of their traditional-configuration entomological radar, allowing automated counting

PII: S0168-1699(02)00011-X

of targets and estimation of their speed and direction of movement. Their technique greatly reduces both the observing and the analysis effort required and also generates more objective estimates of migration parameters. It is compatible with, and will be incorporated into, a fully automated operating procedure that these authors are now developing. In the next three papers, radars employing a more novel vertical-beam configuration that is easier to automate are described. These units operate unattended and can observe migration almost continuously for years on end. Drake et al. describe the remote operation of two such radars in inland Australia, hundreds of kilometres away from their project's base laboratory in the city of Canberra. Results from these autonomous units are downloaded daily over the public telephone system and promptly made available to locust managers and other users via a World Wide Web site. Chapman et al. show how the masses of the migrants can be estimated from the properties of the echo signals, with an accuracy of a factor of two over a range of three orders of magnitude. They also estimate the volume sensed by their radar and use it to determine aerial densities of insects within selected mass categories. In their second paper, Drake et al. describe a secondary observing mode that allows their radars to detect the wingbeating of the targets. They extract not only the fundamental frequency, but also its magnitude and harmonic content, in the expectation that these may provide additional information about the identity of the overflying insects. They also investigate other information that can be retrieved from this second observing mode—the speed of the targets and a lower limit on their size, and compare these results with estimates of the same quantities derived from primary-mode observations. All the radar papers are illustrated with datasets that demonstrate the improved statistics and longer time series that digital technology and automated operation make possible.

Working on a scale of tens rather than hundreds of kilometres and using indirect evidence rather than direct observations, Rochester et al. draw inferences about insect population movements between management units in a mosaic agroecosystem. They analyse datasets of pest abundance and distribution obtained during routine monitoring by commercial plant-protection operators, using modern database and statistical-analysis software and a hypothesis-testing protocol. Time-series, spatial and comparative (season-to-season or region-to-region) analyses and biological models of development and mortality are all drawn on to provide indications of whether an observed population change could have arisen autochthonously (the null hypothesis) or only through immigration or emigration.

At a scale of hundreds of metres, alternative direct observation methods, in which the insect carries an active or passive tag, become practicable. All such methods are constrained by the small size of the subject species and their very limited capacity to carry weight. Riley and Smith describe a 'harmonic radar', in which a passive tag acts as a frequency-changing transponder that allows low-flying insects to be detected even in the presence of ground features and vegetation that produce massive obscuring echo at the radar's transmitted frequency. By avoiding the need for a battery, tags as light as 1 mg can be fabricated and the flight paths of insects of honeybee size and larger can be recorded over an area of ≈ 2 km diameter centred on the radar. A radar display has been developed to plot the target's movements in real time over a background that shows the extent and position of relevant ground features. Hedin and Ranius have followed the alternative strategy of 'radio tracking', using a lightweight (480 mg) active tag and an easily carried receiver which they use to relocate large (≈ 2 g) tree-inhabiting beetles once each day. The tagged beetles remain flight-capable and are often found to have moved into a different tree; the species makes use of tree hollows and on occasions the tag signals are detected from within tree trunks. Maximum range of detection is limited to 330 m over dry, clear terrain and miniaturisation has not yet advanced sufficiently for this technique to be used with any but the very largest of insects.

When observations are to be made not in the field but in a laboratory flight cage, the tag complexity can be significantly increased because detection ranges of only 10–20 m are satisfactory and batteries need last only for the duration of the experiment, often < 1 h. Kutsch has developed tiny frequency-modulated transmitters that can be carried by desert locusts and which telemeter electrophysiological data (muscle potentials) as the locust flies. Miniaturisation has now reached the point where two 200 mg transmitters can be carried, allowing simultaneous monitoring of two muscle-activation sequences; synchronous video observations allow these sequences to be associated with particular flight manoeuvres. The free flight which telemetry makes possible eliminates the constraining forces that can compromise more conventional, tethered flight arrangements.

When observation ranges of only a few metres are satisfactory, video technology—often in conjunction with red or near infra-red illumination—offers very effective detection and data-acquisition capabilities. Short-range movements, either in the field or in a laboratory arena, can be observed even for small insects and recording facilities allow experiments to continue for long durations without the need for an attending observer. However, analysis of the resulting data remains potentially extremely time-consuming. Noldus et al. have produced a computer-based system that can automatically identify and document the movement behaviours and interactions of insects in video image sequences. The system, which is available commercially, provides an integrated platform for developing and analysing behavioural experiments. It has been employed in a variety of entomological research projects, including studies of movement or orientation responses to potential mates, hosts (of parasites), plant volatiles (by herbivores) and illumination patterns. Hardy and Powell describe their use of video to study aphid feeding and flight behaviours, both in a wind tunnel and in the field. They have also ingeniously adapted the technology to study flight behaviour typical of migration at high altitude. They do this by creating in the laboratory a virtual flight environment that maintains the study aphid within the video's field of view for long periods, by regulating a downward airflow so that it counters the insect's rate of climb. The feedback signal controlling the airflow is derived automatically from the video image, which also records any responses of the aphid to a stimulus (a green light that mimics possibly favourable habitats) that in certain circumstances will cause it to terminate its flight.

A different type of virtual environment features in the apparatus developed by Sakuma for studying responses of a moth to pheromone sources a few metres away. In this case, the insect is flightless and movements are ambulatory on the top of a 'servo-sphere' which is repeatedly rotated to retain the walking insect at the top of the sphere. A downward-looking video tracker provides the feedback signals that drive the two-axis movements of the sphere and the insect is enclosed in an airflow chamber that covers the top of the sphere. Air passes continually through the chamber, but pheromone is released into the flow only when the moth is heading in the direction that a 'virtual' pheromone source lies from the moth's current virtual position, as computed from the feedback signals. This direction need not necessarily be that from which the air enters, i.e. not upwind. The moth's track, which is much longer than the diameter of the experimental chamber, can be analysed for directivity etc. In another study of short range movements—this time within the structure of a single plant and from one plant to its nearest neighbours—Hanan et al. rely entirely on simulation. Their sophisticated computer model incorporates growth of the plant, movements and feeding of herbivorous insects on it and responses of the plant to insect damage and may in future include mortality due to predators. This 'virtual ecosystem' provides a laboratory to explore insect–plant interactions and for estimating the efficacy of pest-management interventions or prophylaxes. Such simulations obviously need to be based on reliable system parameterisations and the Guest Editors rather expect that initially the main value of this approach will arise from the stimulus it may provide for identifying the key ecosystem parameters and determining them through field observations.

The contributions described above do not, of course, represent the totality of work on insect movement that employs physical-science based and information technologies, but this is largely summarised in the concluding review by Reynolds and Riley of the recent literature. The review focuses on techniques not covered elsewhere in the issue and identifies methods that employ sensing or imaging technologies, both active and passive, that garner information from electromagnetic waves (from X-rays through to radio frequencies) or from emitted or reflected sound. Devices that have been developed include sensors (for both exposed insects and those burrowing within a food item or the soil), imaging systems, automatically-reporting traps, instrumented beehives and a variety of laboratory rigs, such as actographs, flight mills, wind tunnels and treadmills that allow experimentation under controlled conditions. In some of the latter, direct wire connections are possible and a series of physiological and physical parameters can be monitored simultaneously, permitting sophisticated analyses of locomotory mechanisms. The review also touches briefly on the use of airborne and satellite-borne remote-sensing instruments for observing insect habitat.

Instrumentation and physical science-based methodologies tend to be marginalised within the (non-medical) biological sciences and in entomology at least, often receive budgets that are small in comparison with those of system developers in physical and engineering disciplines. The recent advent of inexpensive personal computers and data-acquisition systems that work with them is now allowing many previously unaffordable technologies to be adopted by researchers working on insects. Automation, large reductions in observer and analysis effort and major improvements in data quality are recurring themes in the papers published here and arise directly from the 'digital revolution' and the accompanying more general proliferation of affordable electronic technology. In at least two cases (Hardie and Powell's vertical wind tunnel and Sakuma's 'servo-sphere'), methods originally developed decades ago have been resurrected now that new technology has made their use in sustained experimentation tractable. The technical expertise to develop novel instrumentation systems nevertheless remains expensive. Too often, support is provided only for a limited term and the opportunity to get beyond the prototype or 'proof-of-concept' stages and to really explore, exploit and develop the capabilities that a novel methodology can offer is lost. Custom development of highly specialised equipment is not an appropriate activity for many entomological research teams: co-operative ventures between specialist instrumentation groups and field or laboratory entomologists will usually be more fruitful. Collaborations between equipment developers also need to be encouraged and would make desirable combinations of observing techniques (e.g. supporting an insect monitoring radar with aerial sampling using radio-controlled micro-aircraft) more readily realisable. When organising the ICE symposium, it became apparent to the Guest Editors that activity in the field occurred overwhelmingly in small groups that had little awareness of what others are doing. The lack of a regular conference and discipline-based publication in a wide variety of journals are obvious factors in limiting the exchanges and cross-fertilisation between groups that would surely enhance their research productivity. We hope that, with the symposium and this Special Issue, we have gone some way to improving communications between disparate groups. We also hope that 'Computers and Electronics in Agriculture' will come to be seen as a suitable forum for publication in this field, at least by those of us—the large majority—whose efforts are ultimately aimed at lessening the impacts of insects on agricultural production or (in rather fewer cases) lessening the impacts of agricultural production on the diversity of our insect fauna.

Acknowledgements

We are grateful to the journal and to Elsevier for approving this special double issue, to Editor-in-Chief Sidney Cox for his advice and encouragement and to the authors and reviewers for promptly submitting and returning their papers and comments and, in the case of several authors, being prepared to recast their papers significantly when asked to do so. We would also like to acknowledge the roles of Dr D.R. Reynolds in co-organising both the symposium and this volume and of Professor R.E. Stinner of the ICE Scientific Committee in supporting the symposium proposal.

Joseph R. Riley
Plant and Invertebrate Ecology Division,
IACR-Rothamsted,
Harpenden,
Hertfordshire AL5 2JQ,
UK
E-mail: joe@radarent.freeserve.co.uk

V. Alistair Drake
School of Physics,
The University of New South Wales at the Australian Defence Force Academy,
Canberra,
ACT 2600,
Australia
E-mail: a.drake@adfa.edu.au