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The Rothamsted Insect Survey Strikes Gold

Party time

On 29th April, the Rothamsted Insect Survey (RIS) celebrated its 50th birthday. Current and past staff, volunteers, funders and dignitaries participated in a day of reminiscing and looking forward. Ian Woiwod, former Head of the RIS provided an introduction entitled "The mythology of the Rothamsted Insect Survey", tracing its origins back to the Egyptian pyramids. Richard Harrington outlined the uses to which the suction-trap network is put today and Mark Stevens, Lead Scientist of the British Beet Research Organisation, highlighted the importance of the RIS to the agricultural industry. There were plenty of posters and artefacts to view at lunch time, although renewing acquaintances and making new ones took priority. The truly amazing birthday cake was the talk of the twittersphere. It was cut by Ian Tillotson, our longest serving

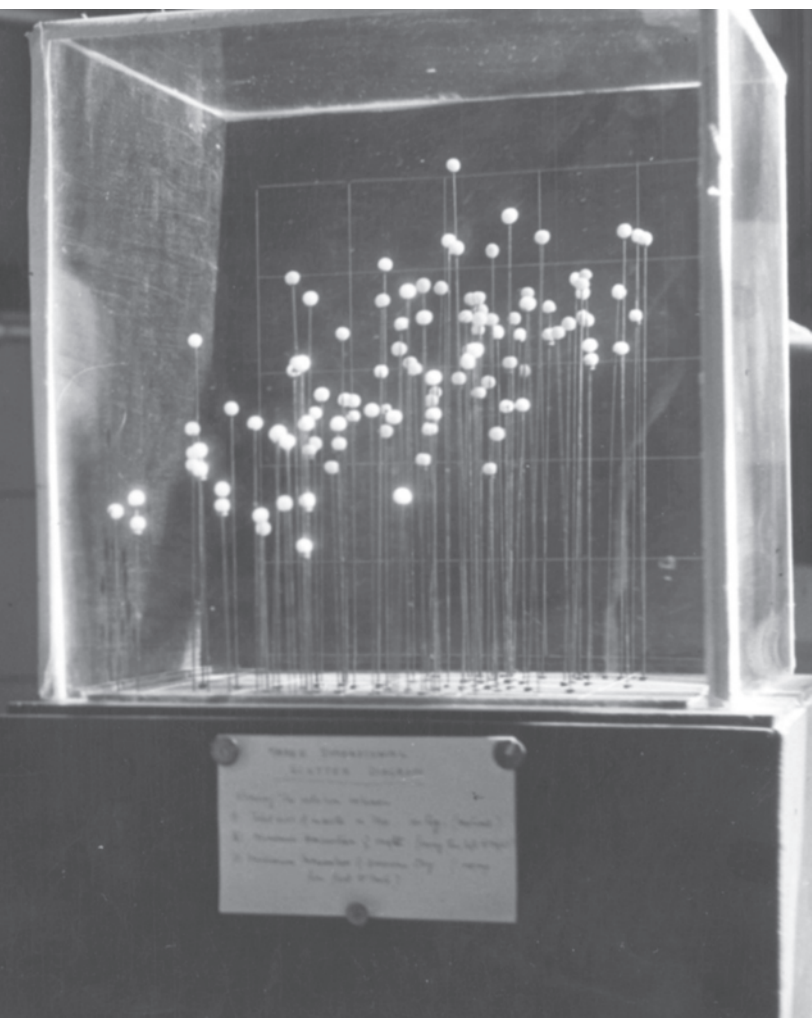
volunteer, who has clocked up 46 years of light-trap operation and around 200 trap-years of identification. Volunteers are the cornerstone of the RIS and each of those present received a certificate of thanks, as did all others who had ever emptied a light-trap or suction-trap. Tim Benton, University of Leeds and UK Government Adviser on food security, opened the afternoon session by describing how the RIS contributes to knowledge aiding ecosystem service provision and how much more information is still locked up in the samples waiting to get out. Chris Shortall, RIS Chief Ecologist, gave an update on the uses of the light-trap network and Martin Warren, Chief Executive of Butterfly Conservation (BC), outlined collaborations between BC and RIS which have led to an improved understanding of changes in moth abundance and pointed to mitigation options. A commemorative

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Early days- Johnny (standing) and Roy working on a suction-trap (left); Health and safety regulations were less stringent (right).



CB Williams and a 3D model that would be produced by a computer in seconds these days.

plaque was unveiled by Robin Taylor (Texas A&M), son of RIS founder Roy, helped by Harpenden Town Mayor, Councillor Rosemary Farmer. The Rothamsted bar provided refuge for further conviviality prior to a well-attended public open meeting in the evening.

History

The birth date is a moot point. 29th April was chosen because on that day in 1964 the first RIS 12.2m suction-trap began continuous operation at Rothamsted, but much was already happening and years of work had gone in to reaching this landmark. The Entomology Department (as it was called then) at Rothamsted had a long history of studies on insect migration, ecology and population dynamics, notably through the pioneering quantitative work of C.B. Williams FRS ("CB"), President of our Society 1947-48, and C.G. ("Johnny") Johnson. In 1948 CB and Johnny recruited L.R. (Roy) Taylor to help investigations on the population biology of insects of importance to agriculture. Roy realised that insect migration is crucial to their population dynamics. He needed good data from around the Country to develop the mathematics of spatial ecology. He and Johnny had designed suction-traps to help understand population dynamics, particularly of the black bean aphid, *Aphis fabae*. Then the publication of Rachel Carson's "Silent Spring" in 1962 led to huge concerns over the environmental impact of pesticides. The government made funds available through the Agricultural Research Council (ARC) for research into what is now termed integrated pest management. Realising the potential of a thorough understanding of population dynamics in relation to rationalising the use of pesticides, Roy proposed a network of 12.2m high suction-traps as an early warning system and predictive tool, and the ARC enthusiastically embraced this idea. In the meantime Roy had resumed studies on moths at Rothamsted using the light-trap design of CB. The trap at Barnfield (on the Rothamsted Estate) was operated by CB from 1933 to 1937 and again from 1946 to 1950 (during the war, the use bright lights was somewhat frowned upon!). Roy brought it back into operation in 1960 and it has run continuously ever since. In 1965 and 1966 two further traps were installed at Rothamsted. By 1968, 60 traps were in

place, well distributed across the United Kingdom.

The power of long-term datasets and the range of applications to which they can be put increases with time. Fifty years is short compared to some of Rothamsted's classical field experiments, but the aphid and moth sampling provide the most extensive standardised data for any terrestrial invertebrate groups anywhere in the World. Many of the uses to which the data have been put could not have been foreseen at the inception. "Climate change", for example, hadn't been invented! This versatility is what has enabled the RIS to survive the funding attrition that has pervaded science since the 1980s. The ARC became the AFRC and then, twenty years ago, the BBSRC. From 2012 the RIS has been funded as a BBSRC National Capability, with much needed support from the agricultural industry, especially the British Beet Research Organisation and the Home Grown Cereals Authority, and from Rothamsted's Lawes Agricultural Trust. The data have also formed the basis of a wide range of specific research projects funded by BBSRC, NERC, Defra (Natural England), the EU and others.

Roy retired in 1984, leaving the suction-traps in the very capable hands of Mark Tatchell and the light-traps in those of Ian Woiwod. Mark left in 1993, handing on the baton to myself, and Ian left in 2008. The light-trap network is now managed by Chris Shortall. Many other wonderful people have, of course, been essential to the success of the group.

International dimension

Suction-traps of the Rothamsted design were soon deployed by aphidologists in other countries, first France under the direction of Yvon Robert (INRA Le Rheu). Funding was mostly provided by the governments and industry bodies within individual countries, leading to collaboration only being possible on a rather *ad hoc* basis. Roy and Yvon recognised the value of standardising the procedures used in the aerial sampling of aphids. In 1980, travel funds provided by the Commission of the European Communities (CEC) enabled them to organise a meeting of interested parties at Rothamsted, which led to the informal EC Experts' Group known as EURAPHID, and to the publication of

a handbook aimed at the rapid identification of winged aphids (Taylor, 1981). EURAPHID meetings were subsequently held at Brussels-Gembloux, Belgium (1982) (Bernard, 1982); Montpellier, France (1985) (Cavalloro, 1987) and Catania, Italy (1988) (Cavalloro, 1990).

After that, there was no funded co-ordination until the establishment in 2000 of the EU Thematic Network, EXAMINE (EXploitation of Aphid Monitoring IN Europe). The seeds of EXAMINE were sown at the Fifth International Symposium on Aphids held in 1997 in León, Spain. At this meeting a workshop on suction-trapping was convened (Harrington, 1998). The meeting led to a reinvigoration of international collaboration which resulted in a successful application to the EU Framework Programme 5. The main purposes of the project were to establish a common database for deposition and retrieval of data from the suction-trap network and to use these data to examine the impacts of climate, land-use and pollution on the dynamics of aphids. Many publications resulted (e.g. Cocu *et al.*, 2005a,b,c; Harrington *et al.*, 2007). Further details on the EXAMINE project can be found at www.rothamsted.ac.uk/examine.

The EXAMINE database is still functioning but, once funding for EXAMINE ceased in 2003, few new data were added other than by the UK and Czech Republic. At a Europe-wide scale the database is now incomplete, and out of date technologically. At Rothamsted, a new, more versatile database is being developed by Paul Verrier. In the past two years this work has not been funded and has relied on voluntary effort by Paul.

Last November a meeting was organised at Bäckaskog, Kristianstad, Sweden by myself and Roland Sigvald, long-term friend and colleague from the Swedish Agricultural University, Uppsala, to attempt again to reinvigorate international collaboration. Delegates from 12 countries including China, South Africa and New Zealand attended (in spite of the best efforts of the St Jude's Day storm), provided an update on the status of suction-trapping in their countries and presented their work to a meeting of the Nordic Association of Agricultural Scientists (NJF, 2013).

The new database (known as "Paul") was presented at the Bäckaskog

meeting and all delegates recommended its adoption as a databank and as a means to facilitate collaborative analyses. As with EXAMINE, the database uses Microsoft SQL Server. All Rothamsted aphid and moth data from the suction-trap and light-trap networks have been uploaded to the new database. The EXAMINE data have also been uploaded. The database contains a complete nomenclature for all included taxa, host-plant information and metadata on the traps. A menu of predetermined retrieval options is currently under development and will allow tabular or graphical output. Once the retrieval system is completed, a JAVA application will be developed to make the data available via the internet in a password-protected environment with appropriate access agreements.

Greatest hits

Data from the RIS have been put to a wide range of uses. Here we provide a simple statement on what we consider ten of the most important fundamental or strategic discoveries, and references to further details.

Taylor's Power Law (Taylor, 1961; Taylor and Taylor, 1977; Taylor and Woiwod, 1980; 1982; Taylor *et al.*, 1978; 1980; 1983)

The discovery of the power law relationship between variance and mean is essential to sequential sampling programmes. Although the discovery was made prior to the inception of the RIS, one of the key early uses of the RIS data was to investigate the relationship further and seek an underlying mechanism.

Diversity statistics (Taylor *et al.*, 1976; Taylor 1978)

Taylor used the temporal replication in data from the light-trap network to compare a range of methodologies for describing diversity and concluded that the log series diversity index, α , was the most powerful discriminator being less affected by sample size and dominant species than other widely used statistics.

Density dependence (Woiwod and Hanski, 1992)

The RIS data enabled the incidence of density dependence in 5715 time series of annual abundance of 447 species of moth and aphid to be examined. This

analysis showed, for the first time, the critical importance of long time series in the ability to detect this important cornerstone of population dynamic theory. Density dependence was detected in 79% of the moth and 88% of the aphid time series longer than 20 years.

Neutral Theory (Mutshinda *et al.*, 2008) Hubbell (2001) developed a controversial theory to explain the dynamics of biodiversity. This "unified neutral theory of biodiversity and biogeography" was based on the assumption that trait differences between trophically similar species had no impact on their relative abundance or speciation rates. Data from the light-trap network were used to test a version of Hubbell's neutral model. The model did not fit the data well because ecological communities fluctuate more than expected under neutrality.

Trait ecology of aphids (Bell *et al.*, 2012)

The annual populations of 170 aphid species were characterised in terms of abundance and distribution in time and space. Functional traits such as life-cycle type and host-plant geographic range sizes explained macro-ecological patterns better than did taxonomic relatedness.

Winter mortality of aphids (Bale *et al.*, 1988)

Various authors had shown aphids to supercool and to freeze at temperatures below -20°C. It was assumed that they could survive such low temperatures, but data from the suction-trap network suggested that temperatures much higher than this were causing significant mortality to the mobile forms. Laboratory investigations showed that aphids die at temperatures much higher than those at which they freeze (pre-freeze mortality), probably as a result of membrane disruption. This is a good example of how patterns in long-term data can lead to testable hypotheses to establish causality.

Climate Change (Woiwod, 1997; Conrad *et al.*, 2002; Harrington *et al.*, 2007)

The data have been used to detect effects of climate and other environmental changes on the phenology and abundance of aphids and moths. Aphid phenology is advancing throughout Europe but more in the case of species

overwintering in the mobile stages compared to eggs. Moth phenology is also advancing, and climate change is implicated in some recent moth declines.

Trophic mismatch (Thackeray *et al.*, 2010)

Holders of long-term datasets often join forces to search for generalities. Data from the light-trap and suction-trap networks were used in a major study of changes in phenology of 726 UK terrestrial, freshwater and marine taxa. Most phenological events advanced with time but those for primary producers and primary consumers advanced more than those for secondary consumers, suggesting that changes pose a threat to ecosystem function because of potential trophic mismatch.

Changes in biodiversity (Conrad *et al.*, 2006; Shortall *et al.*, 2009)

Declines of many widespread and common moth species have been detected using RIS data collected since 1968, with many more moth species declining in abundance than are increasing in southern Britain but not in the north. Total biomass of insects caught in suction-traps declined over a 30-year period in the RIS Hereford suction-trap but not at three other sites (Starcross, Rothamsted, Wye). This is probably related to changes in agricultural practice, which were greater over the period in question at Hereford compared to the other locations. The taxa involved in the decline at Hereford are recorded.

Evolution of plant defences (Züst *et al.*, 2012)

Europe-wide suction-trap data, combined with laboratory selection experiments, showed that defence chemotypes of *Arabidopsis thaliana* are selected according to the relative abundance of two specialist aphid species.

The suction-trap network today

The traps

We operate 15 suction-traps in the UK, each 12.2 metres tall. The traps are emptied daily in spring, summer and autumn, weekly in winter. Aphids are identified at Rothamsted and SASA (Edinburgh), counted, and recorded on our long-term database.



Barnfield light trap

Forecasts and pest control

We have found strong relationships between winter temperature and the time that aphids are first found in our traps, and their abundance. We use these relationships to forecast when movement into crops is likely to start, and to predict the impacts of climate change on pest problems. Compared to 50 years ago, many aphids are flying a month or more earlier.

Insecticide resistance

We test individual aphids, in particular the major pests *Myzus persicae* (Peach-potato aphid) and *Sitobion avenae* (English grain aphid), for their resistance to a range of insecticides. Molecular tools are used to detect the mutations conferring resistance.

Plant viruses

Aphids are important vectors of crop viruses. We detect the presence of certain viruses in aphids and hence their potential as vectors. The traps in Scotland provide data in support of the Scottish Seed Potato Classification Scheme.

Informing pest control

We present all of this information in web and email bulletins which are issued every Friday and used by practitioners to guide aphid control programmes.

Not just aphids

We keep all samples. They are an invaluable resource for studies of, for example, the natural enemies of aphids such as ladybirds and lacewings, wasps, the mosquito vectors of West Nile virus, and the midge vectors of Bluetongue virus of sheep and cattle.

Fundamental science

The data are used in many projects, often aimed at understanding the processes affecting insect population dynamics and community structure.

The light-trap network today

The traps

We currently have 84 light-traps in a wide range of habitats. Each trap uses a 200 Watt tungsten bulb. Most traps are emptied daily throughout the year. The moths are identified by volunteers and by a contractor, counted and recorded

on our long-term database. Samples are not stored.

Moth abundance and distribution

We have shown that two-thirds of our common larger moth species have declined significantly over the past 50 years, especially in southern Britain. This is worrying as moths are good indicators of the health of the environment and are important components of the food chain. However, one third of species have become more abundant. The reasons for the changes are being investigated and will inform conservation strategy.

Not just moths

Other insects have been studied by volunteers on an *ad hoc* basis, resulting in numerous publications, several first records of insect species in the UK and at least two species new to science.

Wider applications

The data are used in a wide range of projects, most of them aimed at understanding population dynamics and community structure in the face of environmental changes, and developing conservation strategies.



The Survey Team (above) and at work (below)

The future

The RIS datasets will continue to be used to answer key fundamental questions in ecology and to support solutions to practical problems in conservation and pest control.

The data suggest that, in general, pest insects are increasing whereas insects of conservation concern are decreasing. We plan to test the hypothesis that features of insects predisposing them to being pests, such as high mobility and potential for rapid rates of population

increase, also make them adaptable to change.

The advance in molecular tools, combined with our wealth of samples, will allow us to understand and predict the interactions between environmental changes and species genetic variability, and their impact on insect population dynamics. Molecular tools may even make it possible to identify and count insects automatically in due course.

Acknowledgements

The RIS has always depended on collaboration between employees and volunteers. We are indebted to all those who have run traps, identified insects, analysed data and contributed to projects over the past 50 years, to those who continue to do so, and to a wide range of funding bodies, especially the BBSRC and its predecessors, who have supported the work. Together we have achieved much and will achieve much more.

Facts and figures (UK)

Total number of aphids to the end of 2013	18,720,533
Largest number of aphids in a year	1,082,509 (1979)
Largest number of aphids in a single trap in a day	51,136 (Broom's Barn, 26 th July 1979)
Largest number of a single aphid species at a single trap in a day	44,736 (rose-grain aphid <i>Metopolophium dirhodum</i> , Broom's Barn, 26 th July 1979)
Number of distinct aphid species identified from suction-traps	478
Largest number of distinct aphid species from a single trap	345 (Rothamsted and Silwood)
Largest number of distinct aphid species from a single trap in a day	86 (Silwood, 4 th June 1974)
Total number of moths to the end of 2013	12,243,842
Largest number of moths in a year	629,868 (1977)
Largest number of moths in a single trap in a night	4,681 (Yarner Wood, 28 th June 1976)
Largest number of a single moth species in a single trap in a night	3,612 (Heart and dart, <i>Agrotis exclamatoris</i> , Yarner Wood, 28 th June 1976)
Number of distinct moth species identified from light-traps	1,535
Largest number of distinct moth species from a single trap	711 (Rhandirmwyn)
Largest number of distinct moth species from a single trap in a night	103 (Yarner Wood, 29 th July 1978)
Peak number of suction-traps	24 (1979)
Peak number of light traps	155 (1976)

Further information

www.rothamsted.ac.uk/insect-survey

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