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General News

David Greathead: a Life in Biological Control

The founding editor of *BNI*, David Greathead, who died on 13 October 2006 at the age of 74, was an influential figure in biological control and also a world authority on Bombyliidae (bee flies). His career reflected many of the changes and developments in biological control over this period, which is hardly surprising since he was central to many of them. A naturally thoughtful demeanour coupled with an encyclopaedic knowledge of biological control endowed him with wisdom and foresight. His legacy includes successful and in some cases groundbreaking biological control initiatives, extensive publications in biological control and taxonomy, contributions to an international regulatory framework for biological control, and last but by no means least the many scientists whose early careers he fostered and some of whom are now well known names themselves. His achievements were a direct result of his rare combination of broad perspective and attention to detail. As fellow-bombyliid expert Neal Evenhuis (Bishop Museum, Hawaii) says: "Everything was thoughtfully prepared and checked and rechecked before he would be satisfied," but as Sean Murphy (a long-serving CABI scientist) says, "David always managed to see the bigger picture." He inspired loyalty and affection in his staff, was excellent company and could spin a great story – his experiences gave him plenty of material to work with.

David Greathead, 1931–2006: he never lost sight of the science (Silwood Park, 1983).

David was born on 12 December 1931 in London, UK, into a family with South African roots: his great-great-grandfather led one of the first parties to be settled by the British Government in the Eastern Cape in 1820, and his great-grandfather was a member of the first South African colonial parliament in the late 1850s. David's childhood was divided between the UK and South Africa, but he elected to stay in the UK for his university education when his family returned permanently to South Africa. He graduated from the University of London's Imperial College of Science and Technology (now Imperial College London) with a BSc in Zoology in June 1953, and was later awarded a PhD and a DSc.

In 1953 he was recruited by Dr (later Sir) Boris Uvarov to work at the Desert Locust Survey (DLS) and, in the words of Cliff Ashall (Officer-in-Charge of one of DLS's field research units) was "introduced to a varied and resourceful set of characters – men of a different breed." While working at the All-Russian Plant Protection Institute in St Petersburg, Uvarov had famously discovered that solitary and gregarious desert locusts (*Schistocerca gregaria*) were different phases of the same species. Having left post-revolutionary Russia, he was recruited in 1920 to the staff of the Imperial Bureau of Entomology in London and was subsequently directly involved in establishing the Anti-Locust Research Centre (ALRC). Uvarov, according to Elspeth Huxley in *No Easy Way* (ca. 1957), not only possessed single-minded drive and deep knowledge of locusts but, crucially, saw that countries would have to work together to solve the locust problem, and strove for this to happen. Over the next 10 years, he and another Russian émigré scientist, Zena Waloff, comprised the entire headquarters staff of the Commonwealth anti-locust effort (and ran this operation at a total cost of slightly over UK£7900). During WWII he advised the highly successful, largely military-based Middle Eastern Anti-Locust Unit that implemented desert locust campaigns in collaboration with the civilian East African Anti-Locust Directorate to protect vital food crops in eastern Africa. Post-war, Desert Locust Survey (DLS) and Desert Locust Control (DLC) took over this role. DLS, which David joined, is described by Cliff Ashall as "one of the more remarkable organisations ever to have operated in East Africa and the Middle East."

Cliff tells how Uvarov chose David "to spearhead the research on locust natural enemies as part of the multi-disciplinary approach to a solution of the locust problem", and this included work contributing to his PhD. He subsequently published a review of the natural enemies of Acridoidea[1] (something he came back to much later in his career) while interest fostered by studies on bombyliid predators on egg pods of the desert locust developed into long-term involvement in biosystematic research on this group. He also studied the effects of biotic factors on desert locust populations and looked at numerical changes in desert locust populations; a paper he wrote with Bill Stower[2] remains one of the few published numerical population studies, and as such is proving important for locust control today.

For the next 8 years David worked at DLS in what Cliff refers to as "that great adventure which was locust research and control." During this time he was involved in field work and research in Ethiopia, Somalia, Kenya and what was then the Aden Protectorate (now part of Yemen). It was not a life for the faint hearted. David described the laborious work on choice of oviposition sites by locust swarms, studies he and Bill undertook with George Popov (another notable Russian émigré locust scientist, and traveller) in Somalia in 1953, continuing in Turkana in northern Kenya in 1954: "We used to delimit groups of egg-pods, scrape the surface and mark them all with matchsticks and then carefully excavate them and plot their position and condition on graph paper." In later years, he expressed regret that the young scientists then involved in locust work had at best a few weeks at a time in the field. From tales he recounted, it is not hard to see why. He and George made a systematic survey of the locust recession areas, beginning with a journey in January–February 1954 from Cape Guardafui, the apex of the Horn of Africa, along the Gulf of Aden coast into Eritrea. The journey was mostly not on tracks and probably not repeated since. They reached Lake Assal, in what was then French Somaliland (now Djibouti). This, the lowest point in Africa at 155 metres below sea level and the most saline body of water in the world, is set in a glistening white salt flat which they had to cross. They found they had to keep up a high speed because the salt crust, below which lay thick sludge, began to break up if they slowed down. Worse was to follow. Near the port of Assab in Eritrea (at the time federated with Ethiopia) and close to the French Somaliland border they stopped to use the radio thinking they were out of sight. But when they set off again they were surrounded by the Ethiopian garrison and put under house arrest until their bona fides could be confirmed from Addis Ababa; the soldiers thought they were the French army come to seize Assab. Moreover, they learnt afterwards, had the soldiers not been holding their topees on their heads with one hand as they came towards them at the double, someone might have been shot, for the soldiers had been told to shoot. Little surprise, then, that David later showed scant regard for, by comparison, minor privations experienced by his staff – and incredulity at the luxuries some biocontrol scientists regarded as essential in the field.

Cliff Ashall remembers David as a "pleasant, cooperative and industrious colleague of great integrity." Nevertheless the locust days gave rise to one of the enduring legends about him, as Cliff recounts. David and Jerry Roffey, a fellow Imperial College graduate, joined DLS at the same time and "spent some time together in Somaliland and Eritrea. There was an Ethiopian locust officer with them who played his radio very loudly in the mornings, something that David did not agree with – and in spite of repeated pleas to turn down the volume it continued until David picked up a 303 rifle and put a bullet through the offending radio." The story became embellished with time and, although apparently exasperated by this, David was known to put it to good use. In the 1980s, while Assistant Director of CIBC (the Commonwealth Institute of Biological Control; IIBC, the International Institute of Biological Control, as it became in September 1985), he was a popular visitor to Kenya and staff would vie with each other to put him up (something that afforded him wry amusement; as he once put it, he had to be careful to share himself around, and was never permitted the luxury of a hotel). These were the early days of personal computers and the dot matrix printer ruled the roost, or in this case the dining room. Eager to clear paperwork before setting off for a day in the field with David, Richard Markham (now Programme Director, Commodities for Livelihoods, Bioversity International) was printing out the results of his late-night labours at breakfast-time. This did nothing to allay David's by-then renowned early-morning grouchiness, and it took but a single grumble about the noise and mess as the paper spewed out into the marmalade for the plug to be quickly pulled and the peace of a Kenya Highlands morning to be restored.

David married Annette in 1958. A graduate of the University of St Andrews in Scotland, Annette was recruited by ALRC in London and then temporarily seconded as a librarian to the International Red Locust Control Service in what was then Abercorn in Northern Rhodesia (now Mbale, Zambia). After their marriage she was to become David's professional colleague too, and her talents were an asset to CABI, both in Uganda where she worked with David on projects, and when they returned to the UK where she earned respect for her meticulous editing – notably for the *Bulletin of Entomological Research*.

David joined the Commonwealth Agricultural Bureaux (CAB, now CABI) in 1962 to set up their first African base with the founding of the CIBC East African Station at Kawanda Research Station in Uganda, some eight miles west of Kampala. As such, James Ogwang (former head of the Biological Control Unit, National Agricultural Research Organization, Uganda) describes him as "the grandfather of biocontrol in Uganda."

The purpose of establishing CIBC stations in Africa was, David later wrote in the opening chapter of *Biological control in IPM systems in Africa*[3], to assist African countries and to find natural enemies for export to other countries. This, as he outlined in the chapter, was during the aftermath of the era when synthetic pesticides had led many countries to abandon biological control, while remaining practitioners often tried to show that biological control was cheaper and permanent. The ease of shipment that air travel afforded had tempted many to economize on detailed ecological studies, and instead ship large numbers of species for release to see which would establish; lessons learnt from an earlier era were forgotten, inappropriate species were introduced, the success rate fell, and biological control came to be seen as something unlikely to succeed and to be used only as a last resort. Against this background, David's emphasis on science-based biological control was invaluable.

Sean Murphy notes how: "From the start it was clear that David saw the need for creating centres of excellence – across the globe – to allow the science to flourish and for it to make a contribution to development", and this was long before 'development' became the buzz word it is today. Gordon Tiley (then Pasture Agronomist at Kawanda, now at the Scottish Agricultural College), describes how David "developed the East African station from practically nothing to a compact unit. A number of young expatriate and Ugandan scientists worked with and were trained by David, who placed particular emphasis on this particular aspect of the Unit's work." Encouragement of young scientists was to become one of David's hallmarks. Gordon also says: "CIBC work frequently took David away on safari to all parts of East Africa in the Unit's Land Rover. Being a small satellite, the Unit was constrained by limited laboratory and library facilities. Conditions for working were frequently technically and administratively challenging, though there was an excellent and comprehensive insect collection. However, with a quiet and organized approach, David sought to promote high standards of scientific professionalism." David's capacity to do excellent work under difficult circumstances could make him a hard act to follow. Ian Robertson (a lifelong friend from locust days) was thinking of David's work in Uganda when, as Officer-in-Charge, CIBC Kenya Station in the mid 1980s, he observed to junior colleagues that it was no point complaining to David about what he was expecting of them, because he had done far better work under far worse conditions and with far fewer resources. This tenacity, which David was to exhibit again and again during his career, was already matched by other traits Gordon Tiley describes that were to become familiar, and remain so, even as Director of IIBC: "He was approachable by staff at all levels and always willing to discuss a problem or to offer level-headed advice, in characteristic measured tones and generally while lighting up or extinguishing his pipe!" Donald McNutt's recollections from when he was posted to Kawanda as an Entomologist in 1967 highlight David's open-mindedness: "My main work was testing the effectiveness of insecticides for pest control and the use of spraying machinery as opposed to biological methods but despite this David was always available to discuss problems with me. In particular he gave useful advice for a booklet I was writing on *Insect collecting in the tropics*." He adds: "He was a realistic person who didn't mind asking me to treat his house against possible cockroach breeding while he and his family went on vacation to South Africa."

Professor Tecwyn Jones (Director, East African Agriculture and Forestry Research Organization [EAAFRO]; later Director, Commonwealth Institute of Entomology [CIE]) says that David "was rightly widely commended for the success of CIBC's biocontrol projects in East Africa." This owed much to his wide-ranging abilities. One of the first projects he tackled concerned the *Antestiopsis* spp. complex, the main pests of Arabica coffee, which demonstrated how David went straight to the root of a problem and had the scientific skill to solve it; in this case, the identity of the pest was unclear. Donald McNutt, at the time working on Arabica coffee pests on Mt Elgon as Entomologist at Mbale, describes David as "a fine entomologist" and was "very impressed by the way he sorted out the *Antestiopsis* spp. complex"; David published a series of papers on this. Subsequent work on the sugarcane scale (*Aulacaspis* spp.) led to the establishment of a coccinellid introduced from Uganda to Mauritius but not control of the pest. However, another coccinellid, *Rhyzobius lophanthae* (syn. *Lindorus lophanthae*) introduced from Mauritius to northern Tanzania was outstandingly successful in the continuous cropping system there and brought the pest under control within 18 months of being released. A (rare) well-funded project on cereal stemborers brought a second expatriate entomologist to the Station from about 1965 (Ed Milner, followed by Ikram Mohyuddin, then David Girling to 1973). David also worked on lantana biological control – a weed that continues to frustrate biocontrol scientists to this day. Insect agents (*Teleonemia scrupulosa*) achieved severe defoliation and dieback, but, David Girling says, "David came to realize that once the insects had knocked it down it just grew again if the land wasn't cleared and used – early IPM?"

Professor Fred Legner from the University of California at Riverside (where he is now Emeritus Professor) spent time searching for natural enemies of the common housefly in Kenya and Uganda in 1966–67, under a joint project he and David were conducting for the US National Institutes of Health. This proved a significant partnership for Mauritius, where *Stomoxys* spp. stableflies were a severe constraint to dairy farming and cattle were kept in straw huts to protect them. First attempts to control flies by releasing New World parasitoids from dung-feeding flies had been unsuccessful in humid inland areas. Subsequently it was discovered the parasitoids controlled dung-breeding *S. calcitrans,* but not *S. nigra* which bred in the plentiful rotting vegetation (notably sugarcane trash) of the humid zone. Fred explains: "After I left, David supervised a study on breeding sites in Uganda. We came up with *Tachinaephagus stomoxicida* out of the work." Between 1972 and 1975, sampling was carried out on banana trash and cut elephant grass. Pupae were shipped to Mauritius for study, and it became apparent that the natural enemy complex was markedly different from that in dung pits. *Tachinaephagus stomoxicida* was released and rapidly established in Mauritius, where it provided substantial control of *S. nigra* for most of the year – a case of careful ecological study reaping benefits.

In 1971 David published *A review of biological control in the Ethiopian Region*[4], the fifth in CAB's Technical Communications series, designed to review the development of biological control in the British Commonwealth. Tecwyn Jones pays tribute to David's wider influence in East Africa: "As head of the CIBC East African Station, David, like all other entomologists in the region, was required to report annually on his work and plans for future research to the East African Specialist Committee for Agriculture and Entomology of the East African High Commission (EHC) – later the East African Community (EAC). I, as entomologist at EAAFRO, chaired that Committee (and submitted its findings and recommendations for approval to the EHC) and perhaps better than most came to know David's value and standing on the committee.

"Throughout his time in East Africa, David was a major contributor to the deliberations of the Specialist Committee and was held in the highest esteem by all his fellow members. Thorough planning, meticulous attention to detail, and immaculate execution of every stage of his work, were the hallmarks of David's own research, and of research projects under his authority. He also enjoyed the highest respect of his peers for his substantial and invaluable contribution to the delineation and work of the EA Plant Import and Export Committee and hence to the EA Plant Quarantine Service with its excellent record."

If what has gone before suggests David was an overwhelmingly serious character, this was not the case. Although he was dedicated to his profession and critical of what he considered poor scientific standards, Tecwyn Jones is keen to stress that there was another side to him: "David will long be remembered by his professional colleagues for his unique contribution to pest-management in East Africa – but no less so by all friends and acquaintances who knew him well for his personal attributes. He was a modest, unassuming, ever-helpful and kind person, whose advice and wise counsel was greatly valued by all. He was by nature rather shy and retiring but his studious thoughtful demeanour belied his keen sense of humour and a quick and healthy appreciation of the ridiculous – a combination which assured his welcome in professional and social gatherings of diverse composition and character."

Gordon Tiley saw similar qualities: "He was a close family man, with wife Annette and children Andrew, Sarah and Emma, plus their affectionate dog, Sheba. They were all popular and active members of the Station community and did much to contribute to its social life. David himself possessed a somewhat dry reserved sense of humour but he was always congenial company. A valuable steadying influence in times of argument or the inevitable personality conflicts among the more boisterous elements in a compact community." Charles Dewhurst, then working under the late Eric S. Brown with African armyworm (*Spodoptera exempta*), remembers visits to Kawanda, where they had one of their light traps, for the typical hospitality with which they were invited for supper by David and Annette. He also recalls David's interest in bombyliids, adding: "David always requested us to bring any specimens of Bombyliidae that we might come across, and that has to be my main memory, as everywhere I have visited in the world, seeing and collecting bombyliids and knowing that David was always interested." Hospitality is a thread that runs through many people's memories of David and Annette. When they eventually returned to the UK and David was based at Imperial College at Silwood Park, they regularly entertained CIBC/IIBC staff and 'Silwood' students, and are particularly remembered for their hospitality to overseas students stranded in the UK at Christmas-time.

David and Annette remained in Uganda under increasingly difficult political circumstances under the regime of Idi Amin until 1973. By then permission to leave the country even temporarily was difficult to obtain, but David managed to extract a letter personally signed by the Minister of Internal Affairs allowing him to leave, with Annette and Emma, to conduct annual field work in neighbouring Kenya (where their two older children were at school). With the CIBC Station Landrover filled with laboratory equipment, and what possessions they could fit in once this was all stowed, they set off, arriving at the border after dark. It was, as David recounted in later years, a particularly tense moment when he handed over the letter. They watched the soldier read it, slowly. They were not sure what to expect next – but it was certainly not what happened. The soldier, clearly awed by the signature on the bottom, asked reverentially whether he could keep it. Bemused, David cordially replied that of course he could. And so they were waved through. But their troubles were not yet over. On reaching Nairobi, the Landrover was broken into and the microscopes stolen; CABI folklore has it that David was reprimanded for his carelessness.

When a new CIBC East African Station was subsequently established at the Kenya Agricultural Research Institute (KARI) at Muguga, the Landrover found a permanent home and the staff cherished it for many years, putting up with its increasingly cranky habits with varying degrees of forbearance until a new breed of four-wheel drive vehicles, of less character but also less likely to shed windscreen wipers in heavy rain, superseded it. Even so it was not forgotten, and at David's retirement dinner at Silwood Park in 1991, Garry Hill, then Director of the IIBC Kenya Station, presented him with the Landrover's wing mirror as a memento.

From East Africa, David moved back to the UK, where he was based until his retirement. One of the first tasks he took on, with David Girling and colleagues at the CIBC European Station at Delémont in Switzerland, was editing a companion to his review of African biological control: *A review of biological control in western and southern Europe*[5] was published in 1976. At first he had an office in the CIE headquarters at 56 Queen's Gate, London, and later he moved to the old headquarters of CAB at Farnham Royal where he was, as Richard Hill (now with Hill & Associates, New Zealand, and on the *BNI* Editorial Board) recalls, "the sole CIBC staff member in the UK at that time and I would visit him at Farnham Royal to seek advice. The move to Silwood and the growing of CIBC UK soon followed, all driven by David." During this period, David Girling adds, David continued with project work; for example surveying in Kenya and Ethiopia for parasitoids of olive pests for Mediterranean countries.

David, with David Girling's assistance on the ground, was also involved with plans for the new CIBC East African Station in Kenya. The agreement for this was signed in January 1981 and it began business in facilities provided by KARI at Muguga, near Nairobi. However, the status of CIBC in the UK was far from assured at this time, but David, as David Girling puts it, "characteristically turned crisis into opportunity, persuading CAB that CIBC needed an information officer (me), a journal to promote biological control (*BNI,* later handing over the editorship to me), as well as an Assistant Director (David) and a new headquarters (Silwood)." Silwood Park formed part of Imperial College's Department of Zoology and Applied Entomology (now Biology), and was home to world-renowned ecological research, and to one of the few MSc courses in Applied Entomology in the UK – a magnet for overseas students. David moved to Silwood in June 1981. David Girling, who retired from CABI and as Editor of *BNI* in 1997 adds, "much of what you see today stems from that time." David's ability to think ahead of his time became familiar to a succession of scientific colleagues over the course of his career. What was less well known was that he came from a family of innovators (and he himself put a good deal of effort into tracing and writing up the family history[6]). To cite but one, David's great-uncle, James Henry Greathead (1844–1896), is known as the 'Father of the Tube' and a statue of him stands outside Bank underground station in London; his improved design for a mechanical shield "made tunnelling deeper, cheaper and safer for the army of workers building the London Underground"[7].

At first housed in a few rooms in the Victorian manor house that was the centre of Imperial College at Silwood Park – in Richard Hill's words – "ensconced in the gallery rooms 'through the looking glass' as I always thought of them", David oversaw the planning and construction of a new IIBC headquarters building in the developing science park, which was opened by Professor M. S. Swaminathan in 1989. David became Director of IIBC in 1989, on the retirement of Fred Bennett, and continued to develop the UK Centre with strong links to Imperial College. His belief, as Sean Murphy puts it, "that good science was the way forward" lay behind the recruitment of Jeff Waage from Imperial College as Chief Research Officer (he became Director after David's retirement). David supported Jeff in the establishment of the Leverhulme Fellowship scheme, a joint CABI–Imperial College initiative that was to produce useful research with applications to biological control. He also took advantage of the proximity to Imperial College to apply his inclusive approach to integration of biological and non-biological control technologies – IPM in short – by developing links with the experts in pesticide application in tropical countries at the college's International Pesticide Application Research Centre (IPARC). Both these were to later prove his wisdom in engaging widely with other disciplines.

David's outward-looking approach is endorsed by many people he worked with over his career. Peter Kenmore (Food and Agriculture Organization of the United Nations, FAO) describes him as: "A real pioneer, and a stalwart for biocontrol, who encouraged diverse approaches so long as they had been field-tested. FAO's first field biocontrol training course in rice, hosted by CIBC in India 25 years ago [in 1982], was made possible because David agreed to our nearly exclusive emphasis on conservation-oriented, rather than 'classical', biocontrol." Harry Evans, a plant pathologist recruited by David from CIBC's sibling institute, the Commonwealth Mycological Institute, CMI (later the International Mycological Institute, IMI), says, "David had the vision to realise that CIBC needed a more holistic approach to biological control, and, despite serious internal reservations, he managed to persuade CABI to invest in a pathology capability. Subsequently, a pathologist was appointed in 1984 to develop projects against both invasive weeds and arthropod pests. More investments followed as specialist facilities were included in the plans for the new building and greenhouse infrastructure in order to handle both low- and high-risk pathogens. This also gave CIBC the opportunity to further enhance its role as a third-country quarantine centre. Thanks to David's legacy, high-profile pathology projects could be undertaken; including the highly successful one against the desert locust – a subject, of course, close to his heart." The IIBC UK Centre grew to have a substantial pathology staff who also became involved in classical biological control of weeds, including the successful control of rubbervine (*Cryptostegia grandiflora*) in northern Australia by a rust fungus; David had first looked for natural enemies of this plant on the Kenya coast in 1973.

The inclusion of quarantine facilities at the Silwood Park site also meant that staff and students based at a UK university were able to study tropical pests. David took advantage of the stability of a managerial role and association with Imperial College to get involved in supervision of research students in the 1980s, including PhD students Aristóbulo López-Ávila from Colombia working on parasitoids of *Bemisia tabaci* and 'Ravi' Raveendranath from Sri Lanka working on *Telenomus* spp. egg parasitoids of *Spodoptera* spp.

David's easy engagement with people created a network of international linkages that CABI benefits from to this day. Dr S. P. Singh (formerly Director, Project Directorate of Biological Control [PDBC], Bangalore, India) describes David's role in the evolution of CABI's links with India. From when he was a post-graduate student in Russia, S. P. Singh had harboured a desire to meet the "stalwarts of biological control from CIBC." His opportunity came in 1984 when, working in Bangalore as a Project Coordinator of the All India Coordinated Research Project on Biological of Crop Pests and Weeds, "I got the news that Dr David Greathead is visiting" and of their meeting he says, "when I met Dr Greathead, then Assistant Director, CIBC, I eagerly explained the activities and the progress of work and also put forth the expansion plan of the project to co-ordinate research, transfer viable technology on biological control of important crop pests and weeds and to serve as a nodal agency for introduction, exchange and conservation of biological control agents at national level. He listened carefully and offered several suggestions, and told me that such a type of expansion requires a lot of public funding." Of this first meeting, S. P. Singh sums David up as "a very pleasant, modest, unassuming and helpful person with depth of knowledge and breadth of vision." Although S. P. Singh was to meet David only once more, they continued to correspond, and he drew on David's published material – notably, he comments, the BIOCAT database. In the years that followed, "collaboration and interactions with CABI improved" and continued to flourish after the formation in 1993 of PDBC with its 16 co-ordinating centres and laboratories. The association has led to joint CABI–ICAR workshops and many other meetings and seminars involving CABI staff – indeed some have become regular visitors and collaborators. Thus, S. P. Singh concludes, "The seeds of collaboration sown by Dr Greathead seem to have germinated and flourished."

Sean Murphy recognizes the importance of David's influence and impact at a personal level: "I met with David in the early 1980s (when I was a student in the UK) when he was already a leading light in biological control. I (and others) quickly learnt that this was a man who had real-life practical experience of trying to get science working for mankind – and who was succeeding – but also (somehow!) managed to keep the 'romance' of the science alive by being a practising scientist and a teacher. This was so important to younger scientists who at that age need to be shown how what they have learnt can make a difference." Sean stresses that alongside all his 'political' and technical achievements was, "David the teacher and mentor. David always had time to discuss and share experiences, and most of all to help." And also, "David the scientist. Once one of my staff in Kenya showed David some (we thought) beautifully prepared insect specimens (from coffee plants) for identification. David sucked on his pipe and after a long pause said, 'Mmm, they need proper labels.' But this was not a critical David – it was just David the professional." Richard Hill remembers with gratitude David's guidance in his early research, when he was a student at Imperial College at Silwood Park but also responsible for the New Zealand Department of Scientific and Industrial Research (DSIR) gorse biocontrol project. He recollects how "a green, early 20-something New Zealand scientist first visited David at Farnham Royal to talk about the gorse project. He was always helpful and full of ideas, and of course I soaked up the stories about biological control history." Richard's memories of those days include "David's good company and droll sense of humour." James Ogwang tells how, also as a student at Silwood Park, "Dr Greathead was a reference for me, perhaps one of the pillars that influenced me to develop interest in biocontrol. I remember him as a simple easy-to-approach fellow who was always smoking his pipe." The significance to biological control of David's encouragement of young scientists is well-illustrated by this, for James went on to be a driving force in the biocontrol effort against water hyacinth in East Africa, and the instigator of the community-based mass releases of *Neochetina* weevils that famously led to the weed's biological control on Lake Victoria in the late 1990s.

David's return to Europe did nothing to dim his enthusiasm for helping developing countries conduct safe and effective biological control. It was one of his motives in championing the need for international guidelines. Increasing environmental awareness had had a double-edged impact on biological control: potential environmental as well as economic non-target effects of introduced biocontrol agents were starting to be seen to be significant; meanwhile, the emergence of IPM, in response to overuse of pesticides, was leading to increased adoption of biological control as its cornerstone. Thus countries with little or no previous experience of biological control were starting to make introductions of biological control agents, both for classical biological control and formulated as biological pesticides. Around 1989, David, on behalf of IIBC, together with the International Organization for Biological Control (IOBC), approached FAO to propose an international code of conduct. As David later wrote[8], "FAO commissioned Professor Michael Way from Imperial College of Science, Technology and Medicine, London, an advisor to FAO on IPM, to prepare a review and discussion document on the need for a code, in association with IIBC and in collaboration with the FAO Integrated Pest Management Programme." With this as the starting point, a worldwide consultative process over the ensuing years led to the development of the code as an International Standard for Phytosanitary Measures (ISPM) of the International Plant Protection Convention (IPPC: an international treaty for protection of plant resources), under the guidance of Dr Gerard Schulten of FAO and with support from David, culminating in its endorsement by FAO member countries at the end of 1995 and formal publication in 1996 as ISPM No. 3[9].

An assessment of ISPM No. 3, conducted by Moses Kairo, Matthew Cock and Megan Quinlan in 2003[10], described its publication as timely: in many developing countries the economic and social factors influencing biological control decisions tended to be more concerned with economic and food security issues than impact on indigenous species. They comment: "It is those mostly developing countries recently starting to use biological control or with an opportunity to use biological control, which benefited most from ISPM No. 3. Until ISPM No. 3 was prepared, there was little guidance available to these countries and none with the international authority that is embodied in ISPM No. 3. [It] gave them increased confidence to proceed, based on the assurance that they were following international standards and procedures." The authors also note that it "has provided a good basis for facilitation of regional projects and dialogue between countries facing similar problems." The authors end by acknowledging that although many people were involved in the process, the efforts of Gerard Schulten and David Greathead were particularly important in seeing ISPM No. 3 through to finalization and ratification. David's thoroughness and patience were key to the ultimate success of an initiative. He himself used to observe ruefully that he was often labelled as pessimistic when he pointed out difficulties with other people's bright ideas; his strength was that he not just foresaw problems, but persevered until ways had been found to overcome them. [ISPM No. 3 was revised and republished in April 2005.]

The quantity and quality of David's publications were recognized in 1977 when London University awarded him a DSc. He continued to contribute significantly to biological control literature, including, with Jeff Waage, *Opportunities for biological control of agricultural pests in developing countries* published in 1983[11], and he edited with Jeff the Royal Entomological Society of London's symposium volume *Insect parasitoids* in 1994[12]. However, a major contribution during this phase, and still used today, was the BIOCAT database. This, according to David Girling, was initially a card database, kept by David, of all introductions of insect natural enemies (parasitoids and predators) for biological control of insect pests worldwide; his wife Annette took over running it when it was put on computer. David recognized, and he and Annette say in their 1992 review of BIOCAT in *BNI*[13], "the results of introductions of agents of classical biological control are of great interest, not only to biological control practitioners, but also to ecologists interested in biogeography, and the process of colonization by invading species, to taxonomists who may encounter unfamiliar species and to conservationists concerned with their impact on native biota."

Notwithstanding his progressive approach to biological control, David had definite ideas about what made a good biological control scientist, and among things he instilled into his recruits was the importance of taxonomy, encouraging them to develop a specific interest. His own interest in Bombyliidae and other Diptera, especially in the Afrotropical Region, was how Neal Evenhuis came across him: "I first became acquainted with David 23 years ago when I was compiling for a book all the published scientific literature of bee flies and was adding to it a short history of its workers." Neal wrote to co-workers he was including, requesting a photo. "Everyone sent me portraits very quickly and without much fanfare, wishing me well in my endeavor. Except David. I had never corresponded with him previously and he said he would get back to me, but only after finding just the right photo. I was baffled by the response. What could he have in mind? I was just asking for a simple portrait. All the photos of the other workers sent to me were the run-of-the-mill portraits or the typical pose by the microscope. Except David. David had a photo done especially for my book. It was of him smartly dressed, smoking his pipe, and his head slightly tilted as though finding something of interest while examining flowers on a shrub. It was the best photo of the bunch and it typified David's method of work." Neal acknowledges David's influence in a way that many will recognize: "He generously took me 'under his wing' as it were and – in addition to letting me in on his incredible knowledge of African bee flies – he also taught me about the necessities of scientific work: patience, thoroughness, and even diplomacy in dealing with co-workers."

Jeff Waage (now Professor of Applied Ecology, Imperial College London) says: "My favourite memory of David was during his time as Director of IIBC, while I was his Deputy, perhaps because he had such an influence on me, when I finally took that role." He realized that, "David was not one of those people who likes management for its own sake. For him, management seemed more of a duty or a service, undertaken in order to support his team, to help us to develop our programmes and to protect us from the whims of the organization above. He was approachable, sympathetic, and supportive, as such a manager would be. He could be a powerful calming force to a fretful scientist. He did this with the aid of a pipe, the filling, lighting and smoking of which created those frequent, thought pauses that turned the crisis into a process of solution."

Jeff also saw characteristics many others have recognized: "The other feature of David's management that left a permanent stamp on the persona of IIBC was his continuing interest in research and the day-to-day business of biocontrol. In so many organizations, you find staff and management tend to differentiate, taking on different interests and priorities. In IIBC, we were all, like David, just curious scientists. He set the example, and that enabled us to all remain one team of colleagues, whatever our secondary management role might be. And he let us all be our own managers – under David, IIBC was a place where you could chase any good idea you wanted, as long as you could find the money. In gentle and supportive ways, David would get involved with many projects."

This was to prove crucial in a ground-breaking project that, not entirely by coincidence, brought David's career full circle (although not in a literal sense) to where it started in Eritrea when, as Eileen Stower described to Cliff Ashall, David first joined DLS and he and fellow recruit Jerry Roffey could often be seen in Asmara "full of the joys of spring careering round the town in the back of a 15-hundredweight truck hanging onto the canopy irons." Jeff Waage picks up the story more than 30 years later: "I remember clearly coffee time conversations [at Silwood] with him and Chris Prior [now Head of Horticultural Science at the Royal Horticultural Society, Wisley], batting about the challenges of locust control, the effect of oils on fungal spores and insect infection in Papua New Guinea, and my rantings about getting enough resources to do successful tropical biopesticide development. And then, eureka, an idea was born that grew and grew and much later became LUBILOSA (Lutte Biologique Contre les Locustes et Sauteriaux). Around other cups of coffee, he would challenge us about classical biological control, drawing from his vast knowledge and his BIOCAT project. Again and again, David contributed while manager to so many of IIBC's most creative moments in his modest way. Gentleman manager and gentleman scientist, he was a very singular person."

The LUBILOSA programme[14], which went on to develop Green Muscle® as a biopesticide for acridids, grew out of concerns about the use of chemical pesticides during the locust plagues of the late 1980s which fuelled a demand for an alternative. A short concept paper by Chris Prior and David in the *FAO Plant Protection Bulletin* in 1989[15] identified deuteromycete fungi as promising candidate pathogens for locust control. From this initial idea, CABI went on to lead, with the International Institute of Tropical Agriculture, a multi-national, multi-institutional team which confirmed that an isolate of the fungus *Metarhizium anisopliae* var. *acridum* (IMI 330189) was the most effective biological control agent available, and developed robust formulation and application technology to allow it to be deployed as an effective biopesticide, Green Muscle®, which has subsequently proved its credentials in many field trials against locusts and grasshoppers in Africa. Commercially produced for the first time in South Africa in 1999, it is registered throughout West and East Africa, and is recommended by FAO for use in environmentally sensitive areas; most recently FAO organized a trial of Green Muscle® against local hopper outbreaks in Mauritania in October 2006. David's early population studies with Bill Stower[2] are achieving new significance: understanding multiplication rates and population numbers is becoming important in deploying Green Muscle® to manage population size in pre- and early post-swarming locust populations.

The significance of David's contribution to LUBILOSA went beyond the belief that biological control could work as part of locust control. The groundbreaking work in the programme was not based solely on the recognition of a suitable pathogen, but also relied on advances in formulation and application technology, so the fungal spores could be formulated as an oil suspension with a long shelf life, and sprayed using standard ultra low volume spinning disk spray equipment. His conviction that biological control should be based on science meant there was support for the recruitment of postdoctoral researchers, such as Matt Thomas (now with CSIRO Entomology, Australia), under the Leverhulme Fellowship scheme to investigate critical features of locust biology and ecology. Roy Bateman (then CABI, now returned to IPARC), who was involved in the application aspects of the biopesticide development, says that "what marked David out was his breadth of view. He was inclusive in his thinking; for example, welcoming of the pesticide scientists and recognizing their value, despite being a world authority on biological control – and this was ultimately to the benefit of the locust programme." Although much of this took place after David retired, it was his knowledge and foresight that allowed it to germinate, and his encouragement of scientists from diverse disciplines that laid the foundations for its ultimate success.

At 60, David came up against CABI's obligatory management retirement age, and against his wishes stepped down as Director of IIBC. However, he was awarded an Honorary Senior Research Fellowship at the Centre for Population Biology, Imperial College London at Silwood Park, and remained professionally very active in biological control and bombyliid taxonomy. He continued to maintain BIOCAT, for example, and kept up a regular flow of information and ideas to *BNI*. Although saddened by some of the changes at CABI, he remained a stalwart support to staff, and as ready as ever to discuss ideas and problems and dispense advice based on his unparalleled knowledge.

Sean Murphy reflects on David's influence: "I think most would agree that as one moves through life, one crosses paths with a few people who end up deeply influencing one's thoughts and even how one approaches a significant part of one's life. David was a leader, a great thinker, and a visionary and path maker and (as the messages I have seen from across the globe clearly show) he had a 'guiding' impact on many people." Speaking for CABI, he adds: "He commanded respect because of who he was and what he stood for. David will not leave us – there is too much of him in what we now do." S. P. Singh echoes these sentiments on behalf of the wider biocontrol community in saying, "the community will continue to traverse the path shown by him." But, in the words of Gordon Tiley, "News of his most untimely death will have been received with shock and sorrow by all who knew him."

We extend our deepest sympathy to Annette and her family at the loss of this most singular scientist, man, husband, father and grandfather.

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By: Rebecca Murphy & Matthew J. W. Cock, CABI.

Evaluating Lessons from Mimosa Biocontrol in Australia

The end of the biological programme for *Mimosa pigra* in Australia is in sight, with the last agent due to be introduced in 2007. This provides an opportunity to reflect on what has been learnt, particularly as the weed is a growing menace in Asia and Africa.

Mimosa pigra is a thorny woody legume that grows up to 6 metres high, and each plant produces thousands of seeds per year. It is native to the Neotropics but now forms impenetrable thickets over more than 800 km^2 of the wet–dry topics in Australia's Northern Territory. It invades both open floodplains (replacing native grass and sedge vegetation) and the understorey of *Melaleuca* spp. woodland, greatly reducing biodiversity. It also invades pastureland, hindering stock movement and blocking access to water.

A biological control programme was initiated against it in 1979 and a number of studies assessing its impact have been published (see sources below and references therein). This article assesses first how successful biological control has been and is likely to be in the future, and then considers other measures that might be integrated with it to help bring about a permanent solution to the *Mimosa pigra* problem.

Evaluation of biological control is vital for improving the efficiency and safety of future programmes, especially as these are likely to involve more stringent testing procedures and release of fewer agents whose selection will be based on predicted effectiveness. In terms of the on-going programme, information on impact is useful for prioritizing redistribution of proven agents and the selection of complementary agents. In addition, successful biological control of woody legumes can take decades, so if evaluations forecast the ultimate success by agents already released, then work on additional agents can cease with a significant cost saving.

Seven biological control agents have been established:

- The seed-feeding bruchid *Acanthoscelides puniceus* was introduced in 1983.
- The twig- and stem-mining moths *Neurostrota gunniella* and *Carmenta mimosa* were introduced in 1989.
- The flower weevil *Coelocephalapion pigrae* was introduced in 1994.
- The geometrid moth *Macaria pallidata* was introduced in 2002.
- All five above agents are now relatively widespread; two more have limited distribution at present:
- The leaf-feeding chrysomelid beetle *Chlamisus mimosae*, released in 1985, established in one location.
- Another chrysomelid, *Malacorhinus irregularis,* was released more recently, in 2000, and has established.

The first agent to be released, *Acanthoscelides puniceus,* was initially found to destroy less than 1% of *Mimosa pigra* seed and was described as a failure. A more recent study put the figure higher, at 10%, and noted that although this would not impact sufficiently on seed production to control established dense stands of the weed, it might impact on expansion if establishment at the edge is seed limited[1].

Results for one of the mining moths, *Carmenta mimosa*, are extremely promising. A 3-year study that compared a range of parameters in sites where it was and was not present[1] found *Carmenta mimosa* associated with a decrease in seed rain, particularly in *Melaleuca* woodland, reaching 90% where agent density was highest. The seed bank was also reduced and, although it was still large enough to allow weed recruitment, *Carmenta mimosa* density was also correlated with cover of competing vegetation. By killing *Mimosa pigra* stems and allowing light to penetrate to ground level the agent promoted development of competing vegetation, which in turn suppressed *M. pigra* germination. Overall, where the agent was present, *M. pigra* seedlings were typically rare or absent and three out of nine stands contracted, and where they were not, seedling density was high and four out of eight stands continued to expand. Thus, as plants senesce, absence of recruitment should lead to stand decline with a time lag of 10–12 years (the maximum age of a mimosa plant). There is also an interesting interaction with fire events (see below). The conclusion of the study was that *Carmenta mimosa* alone can suppress *M. pigra* populations, and to maximize benefits this slowly dispersing agent should be redistributed to infestations it has not yet reached.

This was confirmed by another study[2] that compared litterfall recorded in 1984–86, before agents were released, with litterfall in 2001–03, and correlated the latter with observed agent damage. Although total litterfall was similar in the two periods, it was significantly less at the stand edges in 2001–03. Looking at the components of litterfall, leaf litterfall was 20% higher and seed rain 47% lower (67% lower at the stand edge) in 2001–03; seed rain was reduced by as much as 60% at highest *Carmenta mimosa* densities – and at highest densities of the other mining moth, *Neurostrota gunniella*. Both these agents were most abundant at stand edges.

There have been conflicting reports on the impact of *N. gunniella*. The above results confirmed an earlier assessment, which showed feeding correlated with a 60% reduction in seed rain and a 14% reduction in radial canopy growth over one growing season, while one generation of larvae reduced seedling growth by 30%. This was not taken to mean *N. gunniella* would be able to control *M. pigra* by itself, but it did suggest the agent would be a useful member of a biological control community. However, the other study described above[1] unexpectedly failed to find an impact, possibly because only very large stands of *M. pigra* were sampled and *N. gunniella* impacts almost exclusively at stand edges.

The litterfall study[2] found that *Coelocephalapion pigrae* consumed less that 11% of flowers; its abundance lagged behind variations in flower fall, and there was no correlation between abundance and seed rain. Other data collected supported the view that this agent alone was not responsible for the observed decrease in seed rain. However, the study was conducted in an area with a very marked dry season when few if any flowers are produced. The prediction that flower- and seed-feeding agents would lag behind seed and flower production in such climates is borne out by the lag observed and the absence of impact. *Coelocephalapion pigrae* may be more effective in areas with less marked seasons.

The three most recent releases (*Malacorhinus irregularis, Macaria pallidata* and *Leuciris fimbriaria*) are all leaf feeders, as is the next agent, to be released in 2007. This is an example of theory instructing practice, as a recent modelling study[3] recommended leaf feeders. Data for *Malacorhinus irregularis* are so far insufficient to draw conclusions, but much is expected of it. It has an adult leaf-feeding stage, but its soil-dwelling larvae feed on various plant parts, particularly seedlings and germinating seeds. This 'double-barrelled' strategy means the potential for added impact is great. One study conducted since it established[2] failed to find a significant effect but the evaluation method was probably not the best for this species: although the adults are leaf feeders, its larvae are soil dwelling and adults feed on lower stems by night and shelter in the soil by day and were probably under-represented in trap catches. Hopes are also high for *Macaria pallidata* which is now widespread and abundant[4]. In the laboratory, high levels of herbivory significantly reduced plant growth[5] but quantitative evaluation in the field is required. Although large numbers of *Leuciris fimbriaria* have been released, it is too early to confirm establishment.

Not Just Waiting Patiently

It is clear from what has gone before that biological control is likely to provide a long-term solution for *Mimosa pigra* in Australia. But this is likely to take decades[3], and what happens until then?

Even before the *M. pigra* biological programme was initiated, changes in populations of grazing feral Asiatic water buffalo had demonstrated the importance of vegetation management. Overgrazing by these animals had been blamed for the *M. pigra* invasion. When they were culled and floodplain flora recovered, the rate of discovery of new *M. pigra* infestations fell and an experiment demonstrated that removing competing vegetation enhanced its seedling establishment[6].

One of the field studies described above[1] highlighted the possibility of balancing grazing, fire and biological control. Even after fire, so long as *Carmenta mimosa* was present, stands did not expand and indeed some continued to retreat. The greater fuel load from increasing competing vegetation meant fires were more intense, which in some cases drove back the edge of the *M. pigra* stand. Subsequently the grasses and sedges regenerated and stifled the regeneration of mature burnt *M. pigra,* sometimes almost completely. Stands expanded after fire only where *Carmenta mimosa* was absent. Healthy *M. pigra* is fire resistant so the flames did not penetrate far into the stands; with the competing vegetation burnt, the *M. pigra* stands were able to expand. By altering the susceptibility of *M. pigra* to fire*, Carmenta mimosa* has the potential to reduce its abundance so long as overgrazing does not reduce the fuel load for fires.

Modelling is now an increasingly important component of invasive weed management. The model referred to in the previous section[3] predicted that biological control should enhance the impacts of herbicides, mechanical control and fire. In a field trial integrating biological with other methods[7], herbicides (applied in the wet season in 1989 and/or 1999), mechanical control (crushing by bulldozer in the dry season of the same years) and burning (in the dry season of 2000) were assessed alone and in combination on a seasonal wetland area infested with *M. pigra* carrying abundant numbers of five biological control agents. In isolation, none of the methods was effective, but several combinations were effective; in particular, two herbicide treatments + crushing +

fire (– fire if sharp stumps are not an issue) cleared thickets and promoted competing vegetation that inhibited *M. pigra* seed recruitment; biological control agent abundance was unchanged or increased on surviving *M. pigra* plants. After burning, all agents colonized regenerating plants within a year, although while *Neurostrota gunniella* increased dramatically, *Carmenta mimosa* abundance was reduced. The increase in *N. gunniella* abundance was probably related to its habit of colonizing stand edges: all treatments had the effect of breaking up dense stands into smaller patches with more 'edges', so more plants were susceptible to attack by this agent. The startling features of this study were the speed with which useful grazing land was re-established and the low degree of re-infestation by *M. pigra*. The conclusion was that dense thickets can be controlled by integrating control measures, and that this can be implemented successfully where long-term biological control is underway.

The nature of the replacement vegetation is important, as exotic grasses used in habitat restoration have in some cases gone on to become invasive themselves. In another study[8], a native floodplain grass was identified that regenerated well from stolons following *M. pigra* clearance at a trial site. Natural regeneration can be slow, notably where dense thickets have shaded out all competing vegetation or it has been destroyed by fire, while some *M. pigra* seed can survive fire, germination can be promoted by fire and seeds disperse widely so cleared land is prone to recolonization. Repeated applications of broadleaf herbicides may be necessary before a grass/sedge sward re-establishes and *M. pigra* seed banks (which can have half-lives of up to almost 2 years) have been depleted. However, the native grass *Hymenachne acutigluma,* while re-establishing well, did not suppress *M. pigra*, so other measures would need to be followed assiduously against *M. pigra* seedlings until the floodplain flora has recovered.

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Wasp Fights: Understanding and Utilizing Agonistic Bethylid Behaviour

The Bethylidae is a family of parasitoid hymenopteran wasps comprising three extant subfamilies (Bethylinae, Epyrinae and Pristocerinae) and a total of around 2000 described species. Here we consider their effectiveness as biocontrol agents and especially focus on how studies of agonistic interactions between adult females can be used to both warn of detrimental non-target effects and suggest ways to improve their biocontrol potential.

Bethylids and Pest Control

Bethylids attack almost exclusively the immature stages of coleopterans and lepidopterans, including pests of many important agricultural crops, such as coffee, coconut, sugarcane and almonds, in the field, stored product pests and pests that damage domestic carpets and museum specimens. Aside from a few species that can cause human dermatitis, bethylids can be regarded as beneficial insects and they have been deployed in around 50 classical biocontrol programmes around the world since the mid-1920s. Despite their apparent potential, there have been no biocontrol programmes that have achieved complete pest control (such that no other measures are needed) using bethylid wasps. Overall, establishment of introduced bethylids has been achieved by about a quarter of programmes, with around 5% of the total achieving partial control. The available evidence, however, suggests that the rates of establishment and (partial) success have improved since the 1970s such that about half of the relatively recent programmes have resulted in establishment of released bethylids and around 10% of programmes have achieved partial control of the target pest.

Model Organisms

Despite being underachievers as biocontrol agents, there is a manner in which bethylids have proven undoubtedly beneficial: as study organisms in behavioural and evolutionary research. Parasitoid wasps in general are extraordinarily useful organisms for behavioural and evolutionary ecologists; to some extent this is due to their ease of handling in the laboratory and short and relatively simple life cycles, but the crucial attribute is the direct link between many of their behaviours and their evolutionary fitness. This link is strong because female parasitoids often forage directly for reproductive opportunities rather than for food that will be at some, possibly distant, time in the future be converted into a difficult-to-quantify number of offspring. Bethylids have played an important role in several key areas of parasitoid behavioural ecology research, most notably the evolution of clutch size and sex ratio decisions and also factors determining the outcomes of dyadic contests for indivisible resources. For instance, W.D. Hamilton's seminal work explaining female biased sex ratios in terms of local mate competition (justifiably one of the most famous theoretical advances in evolutionary biology) was bolstered by his knowledge of the sex ratio biology of three bethylid species. Subsequent sex ratio theory was stimulated and tested by empirical and comparative work on numerous further bethylids, leading to a sound understanding of sex ratio precision and the effects of offspring developmental mortality on optimal sex ratio decisions, as well as useful knowledge concerning the relationships between sex ratio and clutch size and the possible influence of some degree of non-local mating ([1] and references therein). Similarly, in clutch size research, bethylids have been used to test theory predicting the 'Lack clutch size', the evolution of gregarious clutches and relationship between offspring size and clutch size[2].

Payback Time

Much of the background knowledge, and indeed some of the data, on which these theoretically-oriented studies were built was gleaned from the taxonomic and biocontrol oriented literature. Reciprocally, an understanding of parasitoid behavioural ecology has great potential to improve biocontrol practice and success. For instance, there are already good examples of the understanding of sex allocation behaviour being used to reduce significantly the cost of parasitoid mass rearing for augmentative biocontrol[3], although it seems that many of the insights generated by behavioural ecology have yet to be fully utilized in biocontrol.

Here we focus on two ways in which initially 'pure' or 'basic' studies of parasitoid contest behaviour have generated results useful, or at least potentially useful, to biocontrol programmes involving bethylid wasps.

Bethylid Contests: Pure

Evolutionary game theoretic models predict that when two animals contest an indivisible resource, the winner will be determined by the interplay between three factors: which contestant is the better (e.g. more able or more powerful) fighter, which is the prior owner, and to which contestant the resource is worth the most. Bethylid wasps, particularly two species of *Goniozus* (subfamily Bethylinae), *G. nephantidis*, a parasitoid of coconut pests, and *G. legneri*, a parasitoid of almond pests, have proven to be extremely useful organisms for testing these theories. On finding a suitable host, a female *Goniozus* first stings and paralyzes it and then stays with it for 24 hours before laying a clutch of eggs onto it. If another foraging female encounters the paralyzed host and its 'owner', violent female–female fights readily ensue, with the loser female being driven away and the winner eventually laying its eggs on the host. These *Goniozus* species also remain with the host after laying eggs until their offspring reach the advanced larval or pupal stage; this is unusual for parasitoids in general but common among the Bethylidae, and owner–intruder contests for host bearing offspring also occur.

By experimentally manipulating differences in size, age, the number of mature eggs stored, and prior owner status between contestant females, and varying the size (quality) of the contested host and the stage of the brood it bears (no eggs, eggs or larvae) the relative importance of the predicted influences on contest outcomes has been established. Differences in female body size are usually of major importance, with bigger females tending to win[4]. This finding led to a theoretical advance connecting size-dependent contest outcomes to optimal clutch size decisions based upon the relationship between body size and parasitoid fitness: even though only one female lays eggs on a given host, her clutch size decision is influenced by the sizes of clutches that other females in the population lay because, on a fixed sized host, smaller clutches give rise to larger offspring which will fare better in subsequent contests for hosts[2]. We have recently found empirical support for this prediction, namely that females exposed to several intruder females before laying eggs reduce the size of the clutches they lay compared to undisturbed females. The above-mentioned empirical studies of contests further showed that outcomes can also be influenced by all of the listed factors additional to body size. These can be interpreted in terms of a difference in the value that the contestant females place on possession of the host[5,6]. Prior ownership status does not appear to be of direct importance but has an effect via the larger number of stored eggs that owners have compared to intruders which enhances their ability to exploit the host thus giving it, to them, a higher value[7]. While there are many other studies of dyadic contests in the animal behaviour and behavioural ecology literature, the particular value of these studies of bethylids is that an unusually large number of many factors contributing effects on contest outcome has been explored, both separately and simultaneously.

Bethylid Contests: Applied

Two issues of ongoing concern to biocontrol practitioners are the question of how many species of natural enemy to deploy to best control a given pest, with the associated danger of detrimental intra-guild interactions, and the dangers of non-target effects of introduced biocontrol agents. Given that multiple species are involved, these are essentially issues at the 'community ecology level' but can be addressed reductively at the 'behavioural' or 'individual' level. Studies of bethylid contests, and associated behaviours, have played a role in evaluating intra-guild interactions in the coffee agroecosystem. Coffee, an originally African crop, is now grown in many tropical regions and is of great economic importance. The principal insect pest of coffee, the coffee berry borer (*Hypothenemus hampei*, a scolytid beetle) also has African origins but has now spread to virtually all coffee growing regions where borer infestations can be intense and coffee production seriously affected. Two species of African bethylids in the subfamily Epyrinae, *Cephalonomia stephanoderis* and *Prorops nasuta*, were released into New World and other coffee growing regions in an attempt to control the borer[8]. Generally, these species established but, typical of bethylids, failed to control the borer sufficiently. Therefore, further candidate agents of biological control were sought. In the late 1980s, *Cephalonomia hyalinipennis*, a bethylid native to North America, was found naturally attacking the borer in southern Mexican coffee plantations. The biology of this 'new' species was evaluated: one encouraging facet of *C. hyalinipennis* was that it is a gregarious species, producing more than one offspring per host attacked (in contrast the two African species released only lay one egg per host) which is predicted to lead to better host population suppression.

In considering whether to encourage, for instance by mass rearing and release, *C. hyalinipennis* in Mexico (augmentative biocontrol) or to introduce it in other coffee producing countries (classical biocontrol) its possible intra-guild interactions with the two African bethylid species were studied. There are many ways in which populations and individuals of different species could interact in an agroecosystem but female–female contests can provide a direct means of assessing the strength and outcomes of inter-specific interactions in the laboratory and thus offer an initial approach to evaluating the possibility of disruptive intra-guild interactions in the field. The three bethylids attacking the coffee berry borer were duly competed against each other, with pairs of females contesting possession of small groups of host inside an artificial coffee berry[9]. It was found that intense contests readily occurred and that the losing female was often killed (*C. stephanoderis* being the most violent and generally successful species). In contrast, when contests were set up between females of the same species, the death of the loser was never observed, even though fighting behaviour appeared to be equally intense. Community ecology theory predicts that species will not be able to coexist when competition is stronger between species than within species: thus oft-fatal inter-species interactions and the non-fatal intra-specific interactions suggest that these bethylids may not be able to coexist ecologically. However, factors other than fighting behaviour may also influence both coexistence and the choice of biocontrol agents to encourage. Investigations of the biology of *C. hyalinipennis* further revealed that it can act as a facultative hyperparasitoid of other bethylids[10], including those deployed against the coffee berry borer (constituting disruptive intra-guild predation) and *G. legneri* and *G. nephantidis* deployed against almond and coconut pests (constituting a potential for detrimental non-target effects if *C. hyalinipennis* were to spread into coconut or almond agroecosystems). A small number of preliminary observations suggest that *C. hyalinipennis* may even be able to win fights against *Goniozus* females, despite being very much smaller, and then hyperparasitize their developing offspring. Studying dyadic contests, normally the preserve of 'pure' behavioural ecology, has thus indicated that the initially promising *C. hyalinipennis* should probably not be encouraged in Mexico nor released as a biocontrol agent of the coffee berry borer elsewhere. More generally, this case history supports the view that when candidate biocontrol agents are screened, consideration may need to be given to potential intra-guild effects and not just host specificity selection criteria.

Bethylid Volatiles: Pure

Until recently, the understanding of bethylid contests was based only on visually observable physical behaviour. However, a few chemically-oriented studies had shown that *Cephalonomia* species can emit a volatile chemical when behaviourally stressed[11]. We recently investigated the occurrence of chemical release by *G. legneri* and *G. nephantidis* (subfamily Bethylinae) and six species in the subfamily Epyrinae (including the natural enemies of the coffee berry borer mentioned above): when artificially stressed the bethylines emit a spiroacetal, called 2-methyl-1,7-dioxaspiro [5.5]undecane (molecular weight 170), while the epyrines emit a methylindole called 3-methylskatole (molecular weight 131). By coupling contest behaviour experiments to chemical analysis apparatus (atmospheric pressure chemical ionization-mass spectrometer, APCI-MS) which is able to monitor continually the chemical composition of the air around interacting wasps we were able to show that, when two *Goniozus* females fight for possession of a host, spiroacetal is usually only released during the most behaviourally aggressive interactions[12]. Once release occurs, the frequency of the most aggressive behaviour is greatly decreased.

Because both contestant females produce and release the same volatile, and thus their natural emissions are chemically indistinguishable, we developed a method of chemical marking by molecular weight manipulation[12]. We reared some females on hosts injected with insect saline made up with deuterated water (heavy water). Deuterium is an isotope of hydrogen, bearing an 'extra' neutron: some deuterium atoms became incorporated into the wasps' bodies during development. We have found no discernable effects on life-history characteristics, such as longevity or fecundity, of the wasps following exposure to deuterium, except that deuterated individuals have reduced fighting abilities but fortunately this effect is much smaller than factors of more biological interest such as differences in body size or ownership status. Importantly, we found that deuterated females emitted volatile profiles that were readily distinguishable from undeuterated females because around 25% of the spiroacetal they emitted had molecular weight raised to 171, i.e. some spiroacetal molecules produced had 17 hydrogen atoms and one deuterium atom rather than the usual 18 hydrogen atoms. This chemical marking revealed that, without exception, it is the losing female that releases the volatile[12]. Although we have currently found no negative effects of exposure to the spiroacetal on *Goniozus*, at high concentration the same chemical has been shown to kill *Drosophila* fruit flies rapidly. Current evidence suggests that *Goniozus* employ spiroacetal released as a weapon of rearguard action to increase their chance of being able to withdraw from a behaviourally aggressive encounter. Given that these encounters will often take place within the confines of small tunnels and cavities excavated by the host, the concentration of spiroacetal could become locally high and thus the contestant remaining near the host could be temporarily incapacitated while the spiroacetal-releasing loser retreats.

This work advanced the study of chemical interactions between organisms because we were able to monitor simultaneously chemical events and physically-observable behaviours. We consider that the technique will be used to study a wider array of chemically related behaviours, such as the attraction of wasps to plant-released volatiles. Deuterium marking also has wider potential, for instance in mark–recapture studies which could help address the well-known problem of tracking the activities of small parasitoids in the field.

Bethylid Volatiles: Applied?

To date the study of volatile emissions by bethylids has been largely 'pure' in scientific nature but does have a link with biocontrol practice. It has been found that when *C. stephanoderis* is mass reared in laboratory facilities for release against the coffee berry borer in southern Mexico, its rate of establishment (in terms of entering and remaining within target berries) in the agroecosystem is very low, seemingly because adult females disperse away from the release site[13]. Such results are obtained if dozens of wasps are collected into large jars in the laboratory and then transported to the field for release. Establishment rates at the release site can be improved five-fold (but still remain low) if berries containing developing wasps are placed in the field, allowing the wasps to emerge and start to forage naturally[13]. Recently, chemical analysis has shown that there is no volatile release in jars containing 20 female C. s*tephanoderis* when the jar is not subjected to disturbance[11]. There are, however, considerable releases of 3-methylskatole within jars that are subjected to one minute of shaking. Given that transport to the field is likely to involve shaking, it is likely that the difference in establishment between naturalistic and *en masse* releases from jars can be explained by the latter method stimulating volatile release which, considering its association with agonistic behaviour, leads to released wasps choosing to disperse rather than remain in the target locality. It seems, therefore, that an understanding of how to reduce chemical release behaviour can improve the efficacy of these wasps in pest control.

Conclusions

Bethylid wasps have proven to be highly useful research organisms in the study of behavioural ecology but only moderately useful as agents of biological pest control. Nonetheless, they are generally beneficial and the greater understanding of their biology gleaned from investigations into female–female contests, volatile release and other areas of behavioural ecology has been, or at least has the clear potential to be, usefully applied to the improvement of biocontrol strategies.

Acknowledgements

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Further information on the coffee berry borer: www.cabi.org/datapage.asp?iDocID=476

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Biocontrol Can Touch Touch-Me-Not

In April 2006 scientists at CABI embarked on the first phase of a biological control programme against Himalayan balsam (*Impatiens glandulifera*) in the UK. Himalayan balsam, also known as touch-me-not, is a highly invasive annual species which has spread rapidly throughout watercourses since its introduction from the Himalayas in 1839. As described in a previous issue [*BNI* 27(2), 32N–33N (June 2006), 'Can biocontrol clear Britain's balsam highways?'], funding was obtained from a consortium of UK sponsors including the Environment Agency, Network Rail and West Country Rivers Trust to conduct the first phase, a scoping study, to determine the feasibility of using biocontrol as a management tool to control Himalayan balsam. The project consisted of a survey, to collect natural enemies from Himalayan balsam in the plant's native range, a full literature and herbarium review and a questionnaire posted to interested stakeholders to attain an estimate of the costs associated with controlling the plant with traditional methods. The survey was a success and a number of natural enemies were shipped back to the UK under quarantine conditions for initial host specificity screening and life cycle studies.

In the UK Himalayan balsam is predominantly a weed of riparian systems where it forms monocultures along river banks, often attaining a height of 2.5 m. Himalayan balsam can outcompete native plant species, reduce biological diversity and, when the plant dies down in the autumn, plant material can become incorporated into the water body increasing the potential for flooding. The autumn dieback also leaves the bank bare of vegetation and liable to erosion. Control, be it manual or chemical, must take place on a catchment scale and preferably start upstream. Often this is fraught with problems due to the sheer scale of occurrence and the division of land ownership which restricts access to areas of the bank. Chemical control near water bodies is restricted in Europe and often difficult to implement due to the inaccessibility of the habitat. The Environment Agency, the UK Government's environmental body, has estimated a figure of UK£150–300 million to eradicate Himalayan balsam from the UK.

Himalayan balsam is native to the western Himalayas (Pakistan and India) with a distribution range of approximately 800 km in length by 50 km wide and at altitudes of 2000–2500 m. For the first phase it was decided to survey Himalayan balsam in Pakistan mainly due to the high levels of damage observed on herbarium samples (Royal Botanical Gardens, Kew, UK) from this area, but also as CABI has a regional centre in Pakistan (in Rawalpindi, near Islamabad) which was a valuable source of local information and an essential component in planning and conducting the field work. The survey centred on the region in and around the Khagan Valley north of Islamabad, where Himalayan balsam is known to be locally common. However, unlike in the UK where Himalayan balsam is found in almost every river system, in Pakistan the plant proved to be highly elusive. Constant searching, 5-hour treks in high altitude mountain ranges accompanied by a police escort owing to the sensitivity of the area, landslides and misinformation all hampered the search, but eventually we were able to pinpoint the exact habitat requirements for Himalayan balsam and the sampling began.

In the native range it was very encouraging to observe that Himalayan balsam was considerably smaller than in its introduced range. It was often found in clusters of 30–60 individual plants and mixed in with other native vegetation as opposed to the monocultures found along river banks in the UK. Every population of Himalayan balsam surveyed exhibited a high degree of natural enemy damage by both arthropods and plant pathogens. Almost all parts of the plant above ground showed symptoms of attack and where both pathogens and arthropods were involved, as was often the case, this combined effect severely damaged the plant. Leafspot damage, indicative of three Coelomycetes species (*Phomopsis* sp., *Phoma* sp. and *Ascochyta* sp.), was exerting considerable pressure on Himalayan balsam populations in the field. Large round 'shot holes' indicative of the damage caused by the leafspot lesions punctured almost every leaf of every plant. Other pathogens, including a downy mildew (Peronosporaceae), a powdery mildew (Erysiphaceae) and a rust fungus (*Puccinia*) were not as common as the leafspot and only found in a few locations, but all were just as damaging.

The rust fungus tentatively identified as *Puccinia* c.f. *argentata* was found in one location in the Khagan valley north of Naron, though it is thought this species would be associated with Himalayan balsam throughout its native range. The 'c.f.' (close to) denotes that an exact identification of this rust was not possible and *P. argentata* was the known (described) species it most closely resembles. *Puccinia argentata* has been recorded on two *Impatiens* species in Europe, *Impatiens noli-tangere* in Central Europe and *Impatiens capensis* in the UK. The fact that this rust species has not been recorded on Himalayan balsam in the UK or mainland Europe, in the latter case where rust-infected *I. noli-tangere* plants grow mixed in with symptom-free Himalayan balsam populations, strengthens the case that either (a) the rust on Himalayan balsam in Pakistan is a different species or (b) it is a different pathotype of *P. argentata*. The potential to use this rust as a biological control agent seems high, though considerable work is required on its host range and life cycle. However, further research is warranted if consideration is given to the behaviour of other rusts on other *Impatiens* species. *Impatiens parviflora*, a non-native species introduced into Europe from Central Asia, is often infected by the highly specific co-evolved rust *Puccinia komarovii* which caught up with its host in the mid 1920s. This damaging pathogen has spread with *I. parviflora* throughout mainland Europe attacking the stems of young seedlings and reducing the seed set and reproduction potential of the plant.

Of the many arthropod species collected, two were of immediate interest due to the high levels of damage observed to be inflicted by them in the field. After initial host range testing and identification the flea beetle *Altica himensis* was rejected as a potential biocontrol agent whereas the thrip species *Taeniothrips major* could be a promising candidate, though more research is needed into its host range. A suite of other arthropods found feeding on Himalayan balsam were collected including four lepidopteran species, two species of coleopteran weevils and numerous hemipteran species. Further surveys are now needed across the whole of the native range of Himalayan balsam to compile a full inventory of the natural enemies associated with this plant species.

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Update on the Spread of an Invasive Ladybird

The spread of *Harmonia axyridis* (variously known as the harlequin, multicoloured Asian or Hallowe'en ladybird or ladybeetle) with particular reference to Europe was outlined in *BNI* in December 2004 [25(4), 81N–82N, 'Ladybird strikes discordant note']. The species had recently arrived in the UK, having flown/blown in from continental Europe, as well as arriving on produce from Europe and North America[1]. In Europe it has been sold since 1982 as a biocontrol agent of aphids and coccids on a wide range of crops and has established in the wild in Germany, Belgium, the Netherlands, France and Luxembourg[2].

Harmonia axyridis has now spread into other European countries, with first records of the species in the wild in Switzerland in 2004[3], Austria in 2006[4] and clear signs of expansion in France in 2004[5]. The species was introduced in Greece but it is not clear whether it has established there in the wild, and in Italy, where it does not seem to have established despite suitable conditions being present[6].

In the UK a detailed monitoring project, the Harlequin Ladybird Survey[7], was set up by the National Biodiversity Network Trust, Centre for Ecology & Hydrology, Anglia Ruskin University and University of Cambridge, funded through Defra (Department for Environment, Food and Rural Affairs). Online recording of the species and extensive national and local media interest enabled wide recording of the species by members of the public. By the end of 2006 over 6600 online species records had been received. Over 40% of these were able to be verified by means of a specimen or photograph. The huge rise in digital photography and use of the internet has made this web-based monitoring scheme both practical and highly successful. Projects for monitoring other invasive species in the future may wish to follow suit.

The spread of *H. axyridis* in the UK has been dramatic[1,7]. In 2004 it was recorded in 14 English counties, all but two in the southeast of the country[7]. In 2005 it was recorded in 24 counties and by the end of 2006 it was found in 41 English plus two Welsh counties[7]. Abundance is highest in the southeast, and in London *H. axyridis* is already being reported as one of the most common ladybird species.

A long-term study of the impact of *H. axyridis* on native ladybird species has begun. Sites around the UK are being surveyed regularly to establish population data on the ladybird species present.

The human nuisance factors reported previously in *BNI* have all begun to be realized in the UK, with large swarms of *H. axyridis* recorded in southern England in autumn 2006. Houses have been invaded by over-wintering ladybirds aggregating in their hundreds, with reports of damage to furnishings by the yellow reflex-blood emitted by the ladybirds as part of their defence mechanism. There have also been one or two reports of allergic reactions to the ladybirds.

The speed of range spread by *H. axyridis* is happening as predicted by Michael Majerus, scheme organizer of the UK Ladybird Survey[8]. It is expected that *H. axyridis* will continue to spread north and west in 2007 and 2008 and that the species will reach

Scotland, as well as further counties in England and Wales during this time.

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Quality Control of *Cryptolaemus montrouzieri* Rearing in Cuba

Early detection and swift action are key elements in combating invasive species. In Cuba, pre-emptive initiatives mean that the country is prepared in the event of any incursion of the pink hibiscus mealybug, *Maconellicoccus hirsutus*. This mealybug is native to Asia and has been spread to other continents such as Australia and Africa. More recently it has been introduced into the sub-region of the Caribbean and North and Central America, but so far Cuba remains free of the pest.

The Cuban national programme for the detection and control of *M. hirsutus* includes technician and farmer training and raising public awareness, exploration for promising native natural enemies in Cuba and the importation of biocontrol agents found most effective in biological control programmes against the pest elsewhere.

As part of the Cuban programme, the predatory coccinellid beetle, *Cryptolaemus montrouzieri*, was imported into Cuba from Trinidad and Tobago because it is an efficient predator for controlling mealybugs, soft scales and aphids.

Cryptolaemus montrouzieri rearing was implemented in Cuban laboratories and quality criteria such as sex ratio, adult length, predatory capacity (determined on mealybugs and aphids), adult deformities and the length of the developmental cycle (egg laying to adult emergence) were included to check the quality of reared insects.

The beetle has adapted successfully to the rearing conditions established and more than 30 generations have been obtained up to now. The laboratory population reared under the quality assessment regime showed effectiveness in aphid and mealybug control and should be maintained. Efforts should also be made to increase its reproductive capacity and thus to set up an efficient, ecologically beneficial and fast alternative to employ in protected cultivation systems and ornamental and fruit trees.

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Down But Not Out: Australian Weed Biocontrol

In less-enlightened parts of the world, weed biocontrol scientists have envied their Australian collaborators for the financial support the Australian Government gives its own scientists, including, in recent years, through the Cooperative Research Centre for Australian Weed Management (the 'Weeds CRC'). However, this changed in November 2006 when the Weeds CRC's application for a third 7-year term was rejected; funding is now due to end in June 2008. This, the Weeds CRC pointed out in a statement[1], leaves Australia "without a national organisation to coordinate weed research and to package and deliver these results to farmers, Natural Resource Management (NRM) regional bodies and other users." If successful, the Weeds CRC would have become the Invasive Plants CRC with funding for the period 2007–2014. In this era of increased invasions and heightened biosecurity concerns, the decision not to fund an Invasives CRC is out of kilter with current opinion – the more so as Australia has long been a leader in both combating plant invasions and developing effective biosecurity measures.

In the January/February 2007 (#152) issue of the respected and widely read IPM email newsletter, IPMnet NEWS[2], Editor Allan Deutsch found a worrying similarity to "events in the UK not so many decades ago", when: "A relatively small group of highly dedicated scientists with great depth of experience and international acumen had established and nurtured what became the world renowned Weed Research Organization. Even with its minuscule budget, governmental entities decided the organization was not generating enough financial payback and, despite a global outcry, summarily shut down WRO. In one ill-advised move, the UK immediately forfeited its weed science leadership position and has not regained it to this day."

The Federal Department of Education, Science and Training turned down the Weeds CRC's proposal on the grounds that it did not meet selection criteria on delivering returns to taxpayers, scientific capabilities, and capacity to commercialize research results and secure their uptake. In reply, the Weeds CRC has argued that improved weed management leads to increased productivity and, in this regard, the Weeds CRC has delivered significant commercial benefits across the whole agricultural sector. This capacity would have increased through the Invasive Plants CRC, with benefits largely delivered through information products, which were under-valued under selection criteria that emphasised direct commercialization processes such as spin-off companies and licensing products. Allan Deutsch finds the list of CRCs successful in this round, "at least to the outsider, thin at best if not woefully devoid of centers of excellence in agriculture pest and invasive organisms management."

In highlighting its achievements, the Weeds CRC points out that it is increasingly "seen as the national voice for weeds research and delivery and its researchers are in international demand in the important areas of herbicide resistance, biological control and weed risk assessment." It adds that, "The economic case for urgent, science-based, national action in weed control is clear. Results from a 2005 Australian Bureau of Statistics farm survey demonstrate that weed control is the largest cost for most agricultural enterprises. Weeds CRC research has shown that at least Au$2b per year is spent on control costs and another $2b is lost through lower yields. Furthermore, weeds are the major issue identified by most of Australia's NRM [National Resource Management] regions."

The Weeds CRC believes that "stakeholders do not want to lose the dynamic and productive system built up over the last 11 years." And it is: "exploring alternative funding models to enable core collaborative research and delivery capacity to continue in the long term."

Amongst messages of support posted on the Weeds CRC webpage devoted to the funding issue[1], Senator Christine Milne declares that, "[The] decision has put an end to the coordination of national weed research programs on the biological control of grazing, cropping and environmental weeds. It has also jeopardised a raft of CRC work on biosecurity, agronomic advice and community education." In a letter to the Education and Science Minister Julie Bishop, the Minister for Fisheries, Forests and Conservation, Senator Eric Abetz, acknowledged that funding was limited: "But I still strongly believe that Australia is losing a great asset in dealing with the problem that costs the agricultural sector at least $4 billion every year. I would be grateful if you could urge those responsible for this decision to reconsider." Senator Abetz is also reported as saying that the government recognises the weed problem and is working with the research centre to see "what other avenues might be available." A spokesman for the senator explains: "If we can't get the CRC over the line, there will be something else put in its place to continue with important national weed research. We still have 18 months to find a solution, and we are looking at all the options."

At present the final outcome is unknown but, as the English cricket team has found out to its cost, Australians fight best when they've previously taken a beating.

[1]www.weeds.crc.org.au/main/weeds_crc_to_end.html

[2]Email: IPMnet@science.oregonstate.edu

Biocontrol and the Californian Cyclist

Occasionally, changes in policy throw up opportunities for a technology to make an impact in a completely new area. In its own small way, classical biological control of a weed can be credited with assisting 'green' transport in California.

Successful classical biological control of an exotic weed does not mean eradication, but reduction of populations to acceptable levels. These can still have impacts which may disproportionately affect particular sectors of a community, as cyclists in California know to their cost. According to a report in *The Davis Enterprise* (22 October 2006)[1], about 80% of punctures brought into one cycle repair shop in Davis in the autumn months are caused by spines on the seeds of the aptly named puncturevine, *Tribulus terrestris*. This annual species has a prostrate creeping habit with stems up to a metre long bearing numerous small yellow flowers; the flowers develop into fruit which bear the damaging sharp and rigid spines.

The situation would be far worse were it not for the biological control exerted by two introduced biological control agents, a stem weevil (*Microlarinus lypriformis*) and a seed weevil (*M. lareynii*), introduced from Italy in 1961. The weevils established readily and spread in California, aided by extensive redistribution of field-collected adults. They were also introduced successfully to other US mainland states, and subsequently to Hawaii and to St Kitts in the Caribbean.

Post-release studies in California indicated a significant level of predation by native species. They also indicated that the seed weevil could in some cases increase flower production. Nonetheless, 15 years after their introduction, the weevils were estimated to have effected an 80% reduction in weed cover and seed production in 1200 field plots monitored throughout the state. A resurgence of the weed occurred in central California in the mid 1990s, prompting a repeat introduction of the agents, and the plant can, as cyclists know, still be troublesome in places.

Puncturevine is one of more than 750 terrestrial weed species covered in *Weeds of California and other western states*. This new two-volume identification manual, produced by Joseph DiTomaso and Evelyn Healy, is sponsored by the California Weed Science Society and published by the University of California Division of Agriculture and Natural Resources (UC DANR)[2]. With its publication in January 2007, this is the most comprehensive weed identification book yet produced in the USA. The two volumes together comprise 1808 pages and contain over 3000 colour photos of infestations and whole plants, as well as close-up photos of flowers, seedlings, and seeds. For each species, detailed descriptions of seedlings, mature plants, flowers, fruits and roots are given, as well information on germination and propagation characteristics and descriptions of similar species. The book is accompanied by two CDs containing all the photographs in the book.

Controlling puncturevine was not without controversy. *Tribulus terrestris* has a native distribution extending through Mediterranean Europe and North Africa. It was first introduced to North America through livestock imports into the US Midwest; the spiny seeds stick to animal coats. It is now widespread in the USA but most common in the southwestern states. First recorded in California in 1902, probably introduced as a contaminant of railway ballast, it spread rapidly along railways and roadsides. It became one of California's most problematic weeds during the first half of the nineteenth century because the tyres of early cars were easily punctured by the spines on the seeds; archival photos show roadsides lined with cars that had flat tyres thanks to puncturevine. The weed also infests agricultural land where the seed interferes with manual harvesting, can cause livestock injury and contaminates others seeds, animal feed and wool – and it is a familiar weed of residential and waste land.

Surveys in the Old World and subsequent field and laboratory studies during 1950–61 suggested the two *Microlarinus* weevils to be the most promising candidates. However, the weevils fed on a wide range of host species, and reproduced successfully on *Tribulus terrestris*, as well as a few native southwestern USA species in the same family, Zygophyllaceae (e.g. *Kallstroemia* sp.). Nonetheless the weevils were approved for release at the time following an evaluation from which it was judged that the benefits of controlling puncturevine outweighed the possible harm the weevils might inflict on non-target plants. Whether this would be the case under today's different regulatory climate is debatable. In the 45 years since they were released, the weevils have been recorded feeding on non-host plants, but have proved to reproduce only on *Tribulus* spp. and closely related Zygophyllaceae.

[1]Hudson, J. (2006) Bicyclists' bane. See: www.davisenterprise.com/articles/2006/10/22/news/070new0.txt

[2]DiTomaso, J.M. & Healy, E.A. (2007) *Weeds of California and other western states*, 2 Vols. UC DANR, Publ. #3488. 1808 pp. Price US$100.00 (discounts on bulk purchases available).
www.calweeds.com

Additional source for this article: Puncturevine pages on Professor F. Legner's 'Discoveries in Natural History and Exploration' website, hosted by the University of California Riverside. See:
www.faculty.ucr.edu/~legneref/biotact/ch-88.htm

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IPM Systems

This section covers integrated pest management (IPM) including biological control, and techniques that are compatible with the use of biological control or minimize negative impact on natural enemies.

IPM Supports Sustainable Coconut-Based Farming

The activities of a multi-donor, multi-national project led by the Asian and Pacific Coconut Community (APCC) mean that coconut farmers in Asia, the Pacific and East Africa will soon have a range of IPM technologies from which to choose. These are being developed and validated in the nine participating countries. Eighty farmer field schools (FFS) have been initiated in the nine countries to empower participating farmers, the majority of which are completed, with some still in progress. Regional differences in pest problems and socioeconomics were identified and are being taken into account. The project also recognizes the wider needs of smallholder farmers, who may grow coconuts as one of a number of crops, and is investigating companion crops and value-added products. For the countries involved, the coconut sector is important to their national economies, but production is currently constrained particularly by pests. By seeking to solve these problems in a holistic way, the project aims to ensure coconut production remains an attractive economic option for smallholder farmers.

The findings of the project so far were summarized at the Dissemination Workshop of the CFC/DFID/APCC/FAO[1] Project on Coconut Integrated Pest Management in Colombo, Sri Lanka on 17–20 October 2006[2].

As a generalization, rhinoceros beetle (*Oryctes rhinoceros*) is the most serious pest in eight of the participating coconut-growing countries (India, Indonesia, Malaysia, Papua New Guinea (PNG), the Philippines, Samoa, Sri Lanka and Thailand); coconut production in PNG is also constrained by the additional rhinoceros beetle species *Scapanes australis,* and Tanzania is ravaged by *O. monoceros*. The eriophyid coconut mite (*Aceria guerreronis*) is a serious pest in India, Sri Lanka and Tanzania. Control measures are being investigated by the affected countries. For example, all nine countries have participated in trials to test combinations of fungal and viral products and pheromone traps, together with basic sanitation, for rhinoceros beetle control (see below). Individual countries have identified other pests, such as red palm weevil (*Rhynchophorus ferrugineus*) and *Plesispa* sp. in Sri Lanka; a chrysomelid beetle, *Sexava* sp. and two 'wild' diseases in various parts of Indonesia; wild boar in Malaysia; a coreid bug, termites, a leaf spot and monkeys in various locations in Tanzania; and the hispine beetle *Brontispa longissima* (a serious invasive pest threatening the Asia–Pacific region) in Thailand and the Philippines; management measures for these are incorporated into country project activities, and are being given a high priority where appropriate. Other constraints, such as drought in Tanzania, also tend to be country-specific, as discussed below.

Control methods for some of the pests were known when the project started, and these have been refined for local conditions. Others in the developmental stage when the project began have been further developed. Yet more have been discovered during the course of the project. Which measures are adopted depends on local factors, including the availability of necessary materials, the stage of the crop, and the economics of coconut production in the different countries.

Rhinoceros Beetle

Rhinoceros beetle (*O. rhinoceros*) has long been recognized as a serious pest of coconut. In Indonesia, for example, an outbreak caused yield reductions to reach 50%. IPM technologies were in use to varying degrees in different countries at the outset of the project, notably application of green muscardine fungus (*Metarhizium anisopliae*) and *O. rhinoceros* virus (*Or*V), and the use of pheromone lures in traps made from dead coconut wood. These have been further developed and refined to meet local needs and conditions. Other new and in some cases preferred methods are also emerging as a result of the project, including, from India, chopping a common weed (*Clerodendron infortunatum*) and adding it to compost and farmyard manure pits to control rhinoceros beetle larvae. Monitoring trees for adult beetles is also proving beneficial, and in Tanzania steel or even wooden hooks have been adopted for extracting beetles from tree crowns.

Metarhizium anisopliae has fulfilled its promise for rhinoceros beetle control. Surveys led to the discovery of 15 new isolates from rhinoceros beetle in the Philippines; a new virulent strain, 'DRC', was identified and is being mass produced. Outreach facilities have been established in India, Indonesia, PNG, the Philippines, Samoa, Sri Lanka and Tanzania to provide training in mass production and use of the fungus, in the expectation that these units will be able to make *M. anisopliae* available on a continuous basis across a large area of each country. Surveys for *Or*V in the Philippines recovered five new isolates; one new virulent strain, 'Dacudao', is being mass produced, along with the most virulent strain from PNG, 'Kokopo'. The project has demonstrated successful on-farm mass production of the fungus in Indonesia, the Philippines and Sri Lanka as well as in other countries. The techniques used for mass producing, inoculating and releasing the pathogens are described in the proceedings, as indeed are techniques for all the technologies developed by the project[2].

Re-infestation by rhinoceros beetle when replanting coconut is always a danger, and measures were developed and trialled to prevent this, including filling leaf axils in young palms and seedlings with naphthalene (the Philippines) or naphthalene and neem oil cake (India and PNG); naphthalene has a remarkable repellent effect, reducing damage to zero in the youngest leaf. Sanitation – digging deep trenches for dumping and burying all coconut trash – has been found effective in Indonesia (see below) and useful on a plantation scale in the Philippines.

In the Philippines and PNG, experimental IPM identified the importance of sanitation and trapping. Coconut logs to be sold as lumber or used as firewood, together with coconut buds for using or selling, were removed from the field. Unusable coconut debris, including the boles, unused portions of trunks, and fronds, was dumped in deep trenches and covered with soil. This was highly effective in reducing beetle damage through removing potential breeding sites. Sawdust traps containing *M. anisopliae* and *Or*V were deployed to spread infection of the two pathogens, and PVC pipe traps with pheromones and sawdust/dead coconut wood acted as effective synergists for trapping adult beetles.

The pheromone traps were a tremendous success. Replacing the pheromone ethyl chysanthemumate with 'Oryctalure' (ethyl 4-methyloctanoate) from Chem Tica International, Costa Rica has been very effective. These measures are now being trialled in farmers' fields and demonstrated through FFS. In the Philippines farmers have taken on this activity themselves, and it has restored their hope for the recovery of their beetle-ravaged coconut economy.

Data from the trial conducted in all nine countries is still being collected. However, there are some promising indications. What works best varies between countries, underlining the need for site-specific regimes: pheromone traps are giving good results particularly in the Philippines (confirming the trials above), India and Sri Lanka, but also elsewhere, while *Or*V shows promise in Malaysia, PNG and the Philippines in particular, and also in other countries; *M. anisopliae* has shown promise in the Philippines and Malaysia, while *M. anisopliae* and pheromone traps seem most promising in Thailand. Importantly, the project has estimated the costs of each technology for controlling rhinoceros beetle in each country.

Coconut Mite

The eriophyid coconut mite (*A. guerreronis*) also causes severe economic damage. In Tanzania, for example, it is reported to cause 20–30% losses in copra production. Neem-based methods have been developed and rated for effectiveness, adoption and environmental sustainability, and have shown promise in India, Sri Lanka and Tanzania. Application methods for azadirachtin include spraying it on bunches of coconuts up to 6 months old, and root feeding. In India, a neem oil/garlic soap mixture has given convincing results: reduced incidence of mites and nut damage, and improved yield potential (through better nut retention) has been observed on demonstration farms. Costs for each option have been estimated for the three countries. Another potential control involved applying used engine oil to 2- to 5-month-old bunches.

Surveys for natural enemies (predatory mites and pathogens) were conducted in India and amongst these, four virulent isolates of *Hirsutella thompsonii* were collected. Natural levels of the fungus were monitored in the field and, while it occurred in all districts surveyed in the Indian state of Kerala, in Sri Lanka it is one of the most important natural enemies of coconut mite. Assessments of spraying with the fungal isolate H-2 have given promising results in Sri Lanka, with coconut mite populations showing reductions in about 6 weeks. Importantly, isolates of the fungus showed no non-target effects on the predatory mite *Neoseiulus baraki* which attacks *A. guerreronis*. Currently, varying frequencies of application are being studied. Large-scale validation with mass-produced fungus has yet to be undertaken.

Coconut-Based Farming Systems and FFS

Other technologies developed for management of coconut-based farming systems have been assessed and successful ones are now being introduced through FFS. For example, in India, experiments on integrated nutrient management compared the effects of applying farmyard manure and growing cowpea (*Vigna unguiculata*) around the boles of coconut trees as a green manure; the plant is dug into the soil at the end of the growing season (September/October) and allowed to decompose. The efficacy of mulching with palm fronds to preserve soil moisture during the dry season was also shown, and a method for worm-based composting of organic waste has been developed. The use of *Ocimum* (the herb basil) and methyl eugenol traps are being assessed for control of mango fruit flies in India, as these were identified as a problem by the farmers. The potential for the shrub *Gliricidia* as an energy crop is being investigated in FFS in Sri Lanka, where intercrops/companion crops, irrigation, nutrient deficiencies/fertilizers and the vital topic of safe pesticide use are also being addressed. Farmer requests led to crop husbandry and nursery practices being included in Tanzanian FFS, while intercropping is part of the FFS curriculum in Thailand.

A variety of income generating technologies has been devised in the participating countries and these are being trialled: from growing oyster mushrooms in coconut waste, and manufacture of coconut thatch and baskets from leaves and leaf midribs, to preparation of a wide range of products from the nuts including many foods and drinks and a number of cosmetics, together with coconut shell and wood carvings.

The FFS element in the project is seen as a particular success. While some countries had a history of implementing FFS and were familiar with participatory methods, they were totally new concepts to others, such as Samoa. Apart from providing farmers with the latest in pest and crop management technologies, other knowledge – about product diversification, compost making and food processing – is also being acquired, especially by farm women, and this is both enhancing income and increasing empowerment of women in these rural communities.

The FFS allow farmers, and their assessments of technologies, to be heard. For example, Indian participants thought the *Clerodendron* weed treatment the best option for smallholders to use to control rhinoceros beetle larvae in compost/manure production and, in their view, *M. anisopliae* would have most application for larger producers. It is what they decide that will ultimately determine which technologies are taken up; by listening to the farmers, future research and training can be honed to meet their needs.

[1]CFC/DFID/APCC/FAO: Common Fund for Commodities/UK Department for International Development/Asian and Pacific Coconut Community/Food and Agriculture Organization of the United Nations.

[2]Singh, S.P & Arancon, R.N. Jr. (eds) Proceedings of the Dissemination Workshop of the CFC/DFID/APCC/FAO Project on Coconut Integrated Pest Management, Colombo, Sri Lanka, 17–20 October 2006. APCC, Jakarta, Indonesia, 268 pp.

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From Wild Pecans to Profitable IPM

The cost of IPM compared to pesticide-based approaches is one reason farmers may eschew IPM. However, a recent survey in the US state of Texas has shown that the Pecan Integrated Pest Management Program has been a financial benefit to both producers and consumers. Very unusually, a large proportion of this crop is still harvested from 'wild' trees, which provided a starting point for developing the IPM programme.

Pecan nuts are the most economically important *Carya* spp. (others include hickories and walnuts) in the USA. Texas is the country's second-largest grower of pecans, producing 13–40 million kilograms per year from some 69,000 ha of improved varieties and native pecans; the variation in the yield is because pecan is a masting species whose wild trees (many of which are also harvested) irregularly but synchronously produce heavy crops in a range of 2–7 years.

Domestication of this wild natural resource began seriously less than a century ago and is still progressing slowly. About 80% of production in Texas came from these semi-domesticated (i.e. land only thinned of competing trees and brush to allow for cattle/pecan based agriculture) wild trees in 1972 and in 2006 production from wild trees still accounts for 50% of production. Wild trees live for 150–200 years and nuts are commercially competitive with improved varieties, if wild trees are already present in abundance. They are not, however, considered economical to replace. Conservation of this currently still abundant natural resource will require deliberate planning soon, or the next century will chronicle the replacement of these natural stands of majestic trees, each genetically distinct from the other, with a few vegetatively propagated varieties currently in vogue, or perhaps some other crop altogether.

As Texas is in the native range of *Carya* spp., most of its pests co-evolved in the same region as the present-day crop. The main insect pests are the nut-damaging pecan nut casebearer (*Acrobasis nuxvorella*) and pecan weevil (*Curculio caryae*), while the crop is also attacked by foliar pests: including pecan aphids (*Monellia*, *Monelliopsis* and *Melanocallis*), gall-makers (i.e. *Phylloxera* sp.) and webworms (*Hyphantria cunea*). The most common diseases are pecan scab (*Cladosporium caryigenum*), powdery mildew (*Microsphaera ulni*) and stem-end blight (causal agent unknown), while weed problems come largely from perennials and Bermuda grass (*Cynodon* spp.).

The basis for the IPM programme emerged (and is still developing) from an attempt to understand how the wild pecan survived pest attack in the natural system and then devising management strategies to work with these natural defence mechanisms whenever possible to conserve commercial production. This 'basic' research, for example, shows that pecan nut casebearer can be ignored with impunity in some years, but must be vigorously managed in others or the entire crop will be lost. Another example concerns the aphid complex: the role of the blackmargined aphid (*Monellia caryella*) in the natural system appears to be to maintain a robust natural enemy complex that, in turn, reduces the threat posed by more insidious pests; spraying for this aphid in response to easily visible accumulating honeydew is discouraged because production is usually minimally affected, if at all, and unneeded insecticide will reduce natural enemies and release the more insidious pests. IPM success requires educating one producer at a time to these and other nuanced approaches involving whether or not to conduct overt management.

Additional problems occur that involve nutritional management requiring use of the spray machine. Trees growing in alkaline soils, as commonly occur in Texas, also benefit from 3–5 foliar applications of zinc annually to remediate deficiency of that element. Zinc can be tank mixed with insecticides and fungicides, and this increases the temptation to prophylactically spray the latter as 'insurance' when needed zinc applications are made in the spring.

Despite these challenges, Texas pecan producers participated in programme development and some began converting from conventional chemical pesticide programmes to an IPM-based programme in the mid 1970s and early 1980s. The Pecan Integrated Pest Management Program is a partnership among Texas Cooperative Extension, Experiment Station, Texas Pest Management Program, Texas Department of Agriculture, Cooperative State Research, Education and Extension Services and producers. Its two major goals were determining at what point it became economically necessary to treat for pests, and then developing and implementing a monitoring programme for use by producers.

Wide-scale implementation of IPM has meant that, since the 1980s, growers have reduced insecticide use by 35%, fungicide use by 30%, and total pesticide applications by 9%. But how did this measure up financially? The Texas Pecan Growers Association, which has some 500 members, sent out a survey developed by entomologist Marvin Harris and extension specialist Bill Ree, both at Texas A&M University, and Alexandra Gomezplata, who was studying for a master's degree there. Analysis of the replies indicated that pesticide use in pecans is an estimated 192,000 kg per year less than in 1980, before IPM was implemented. This equates to a saving for pecan growers of some US$4.4 million per year in material costs. Consumers also benefit because both the environment and the economy are healthier.

According to the survey report, Texas pecan producers have not only reduced the amount of insecticide and fungicide sprays used in the last 25 years but when they use them they time them more precisely. This has reduced the incidence of pesticide resistance in harmful insects but conserved their natural enemies. It has also minimized harmful effects of the pesticide sprays.

According to Marvin Harris, the greatest reduction in insecticide use since 1980 has been seen in the 50% of the growers who spray insecticide but now label themselves 'IPM producers'; nonetheless, self-labelled 'conventional' producers also report using progressively less insecticide in the five surveys conducted since 1980 and the gap separating the two groups has narrowed from 2+ insecticide sprays/year in 1980 to < 0.5/year in 2006.

The survey showed that programme information on IPM from the Texas A&M University System is used by virtually all producers, and most producers also factor in discussions with neighbours in making management decisions. Marvin Harris observes, "The practice of and benefits from pecan IPM are being widely adopted, even if the labels growers identify with are slower to change."

Sources: Chenault, E. (2006) Pecan integrated pest management program pays plenty for producers. AgNews: Texas A&M University System Agriculture Program press release, 15 December 2006: http://agnews.tamu.edu/dailynews/stories/ENTO/Dec1506a.htm

USDA Crop Profile:
www.ipmcenters.org/cropprofiles/docs/txpecans.html

Further information: Texas IPM Program:
http://txipmnet.tamu.edu/index.html
pecankernel.tamu.edu/
pecanspiders.tamu.edu/

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Training News

We welcome experiences of working with the end-users of biocontrol agents or in educational activities on natural enemies and IPM. But the article in this issue is not about biological control: it discusses challenges faced when two very different groups of people (plant breeders and farmers), with different backgrounds and agendas, undertook to work together; the general lessons learnt are more widely applicable.

Learning Lessons from Participatory Breeding Research with Sulawesi Cocoa Smallholders*

The five provinces of Sulawesi produce more than 80% of the national cocoa crop of Indonesia. This production is largely the result of a boom in cocoa farming driven almost wholly by smallholders that has taken place since the 1970s and has brought great economic benefits to this region of Indonesia[1]. Almost all of the cocoa in Sulawesi is now grown by smallholders (around 400,000 in number) on farms of 1–5 ha. Following the initial rapid expansion of cocoa production with very few pest or disease problems, Sulawesi cocoa smallholders are now facing serious problems:

- CPB: Cocoa pod borer (*Conopomorpha cramerella*), a gracillariid moth, is the most important insect pest of cocoa in Southeast Asia. In Sulawesi it causes huge crop losses and has a detrimental effect on bean quality. It is thus regarded by buyers and processors in Indonesia as the main problem facing the Sulawesi cocoa industry.
- PPR: Phytophthora pod rot caused by the fungus-like pathogen *Phytophthora palmivora* can, in particularly wet areas, cause losses exceeding even those from CPB.
- VSD: Vascular-streak dieback caused by the basidiomycete fungus *Oncobasidium theobromae* causes dieback from the branch tips and may severely affect cocoa trees, especially in prolonged dry spells.

Changes in the social landscape of cocoa farming have led to a need for a different approach to pest and disease management. In the late 1800s and early 1900s most Indonesian cocoa was grown on large estates in Java and an outbreak of CPB at that time was controlled successfully by centralized pest management schemes. For example, during times of CPB epidemics, stripping trees completely of cocoa pods (rampasan) was successfully used by Dutch plantation managers to break the life cycle of the pest[2,3]. Using such methods CPB was eliminated from Java[4]. Much of the cocoa in Java is still managed by government-run estates or private companies. These organizations can apply highly centralized programmes of pest and disease control. For example, an intensified campaign of pruning VSD infected branches in West Java in the 1990s resulted in a decline of the disease to negligible levels. However, as mentioned above, most cocoa in Sulawesi is grown by smallholders, many of whom worked as labourers on Malaysian plantations and who, on returning home, established their own small cocoa farms. In fact, the increasing importance of smallholders in cocoa production is typical of a worldwide trend in cocoa farming and now most cocoa in the world is grown by smallholders. Centralized management programmes are not possible or are too difficult to implement. Farmer education and effective dissemination of information to farmers are now seen as the keys to improving farm management. Farmer field schools (FFS) and farmer education programmes have proliferated[5].

In line with an increased emphasis on farmer training programmes, farmer participatory research (FPR) is increasingly being recognized as a useful way of conducting research, with important advantages for technology development, uptake and dissemination. By participation in research on their own or neighbouring farms, farmers are introduced to the problems they are facing and the options available to them to address these problems. Farmers participating in research that tests technologies experience these at first hand and are more likely to adopt any new technologies that work. Participatory research, especially in farmer groups, can result in rapid and effective dissemination of information of new successful technologies to neighbouring and other farmers. It also ensures that research realistically addresses the problems on the farms.

Under the Australian Centre for International Agricultural Research (ACIAR) Project CP/2000/102, Australian and Indonesian institutions, including universities, government research institutions and development organizations and a private chocolate manufacturing company (see author list), have been working in Sulawesi as research partners to test methodologies for on-farm selection and trialing of cocoa genotypes and other technologies with the aim of improving pest and disease control and overall yield and quality characteristics on cocoa smallholdings. The project has been underway since 2001 and was due to finish at the end of 2006. Working in research partnerships is the approach fostered and encouraged by ACIAR. Indonesian government research and estate crop extension officers have led the research process with the support of Australian colleagues. We have also worked closely with farmers and, lately, with farmer groups. This approach is similar to models based on farmer participatory training (FPT) and FPR developed by CABI and other organizations[5]. Here we outline our experience with this approach to cocoa improvement in Sulawesi.

Problems on Sulawesi cocoa farms were approached from the farmers' standpoint. How could farmers and local institutions act to improve production and quality of cocoa on Sulawesi farms and what resources were available locally to achieve this? One resource is the widely spread network of government extension and research services in Indonesia but these have limited funding. A common aim of ACIAR projects is to improve the research capability of overseas institutions and, in line with this, some funding from ACIAR was allocated for training and capacity building purposes, including almost full employment of two Indonesian government officers on the project. A second local resource is the genetic stock of cocoa on farms in Indonesia which is characterized by considerable diversity due to introductions of various cocoa genotypes over a long period of time and hybridizations between them. A third resource is the local knowledge of farmers. Most farmers are able to identify their best yielding trees and, in many cases, individual trees that appear resistant to particular pests or diseases. The ACIAR project's main activity was to encourage farmers and local institutions to select promising genotypes from among the great genetic diversity on farms and to test the usefulness of this approach by establishing trials of selected clones, and some imported clones, on working farms using side-grafting onto mature cocoa trees as the method of propagation. Mature grafts are now being evaluated for performance against pests and diseases, and for yield and bean quality. The trials included some control clones selected as being susceptible to CPB, PPR or VSD. It is expected that following the trial evaluations farmers will be able to retest, on their own farms, the clones identified as the most promising in the research trials. Generally, it is hoped that the project will help to demonstrate basic methods of statistically sound research to Sulawesi researchers and farmers. We hope to show that low-tech methods, basic science and local human resources are enough to conduct productive and rewarding research linked to the real problems on farm. The method of side-grafting onto mature cocoa also demonstrates a way in which less productive cocoa farms can be rehabilitated.

The ACIAR project involved the cooperation of farmers from the selection stage right up to the retesting stage. As discussed below, this has not been without its problems especially as farmers are very diverse in terms of their ability and commitment. Therefore, we found it is especially important to set up cooperative arrangements with farmers who are committed and reliable.

On-farm Selection of Genotypes

Selection of local and promising cocoa genotypes was done with the participation of farmers. Project personnel visited farms affected by one or more severe pest/disease problems in different parts of Sulawesi. Farmers were asked to identify trees that yielded well and/or were comparatively resistant to CPB, PPR or VSD. Clones with both characteristics could be recommended to farmers after testing, while clones with only resistance could be used in breeding activities. Particularly susceptible clones were also identified to act as controls. The genotypes were collected as budwood, propagated by side-grafting onto mature cocoa trees and tested in trials established on farms in South and Southeast Sulawesi. The locally selected clones were named after the contributing farmer. The current results of these tests are mixed in terms of the farmers' predictions, e.g. some clones selected as CPB resistant were mediocre in performance, but there were some successes (although it should be noted that genotypes that perform well in one location may perform differently elsewhere).

- Some genotypes selected with farmers' help for potential CPB resistance showed significantly higher resistance than other clones.
- In Ladongi, Southeast Sulawesi, total (i.e. the sum of light, moderate and severe) CPB infestation rates for selected clones exceeded 80% and in some clones over 40% of pods were severely infested with CPB (determined as when 50% or more beans were irrecoverable). However, a genotype selected by farmer Andi Aryadi had a total infestation rate of 63% with only 5% severely infested.
- A number of the farmers' CBP resistant clones had moderate to high rates of total infestation but very low rates of severe infestation, meaning that most of the beans from these clones escaped severe damage and could be sold.
- Clones identified by farmers as very susceptible to CPB and included as controls were among the most susceptible in the trial.

In general, CPB resistance is hard to identify since nearly every cocoa genotype becomes infested, especially in the low pod season when infestation rates are highest. More success was met with local selections for PPR and VSD resistance.

- Two local selections had a level of PPR resistance comparable to clones widely recognized for resistance (including DRC 16).
- A genotype selected on-farm for VSD resistance was as resistant as two international clones, Catongo (from Brazil) and KA2 106 (one of the most VSD-resistant clones to emerge from the severe epidemic of VSD in Papua New Guinea in the 1960s).
- Again, the susceptible controls for both these diseases proved to be among the most susceptible of the clones in the trial.

In general, some farmers, but not others, could identify superior trees based on their general productivity as well as pest or disease resistance. The results from the trials indicate that testing and evaluation of performance of clones in local environments is important and necessary to confirm the initial observations by farmers and to determine whether some of these clones could be recommended to other farmers as clones that are high yielding in the presence of local pests and diseases.

Establishing Trials on Farms

The ACIAR project in Sulawesi established two major trials on farms in two provinces, South and Southeast Sulawesi, at an early stage in the project and a number of smaller trials with a simple design at a later stage. The larger trials had a single-tree replicate design as commonly used in research on forest trees. They consisted of twenty replicate blocks with each block containing a single representative of each clone under test. Budwood collected from each of about 50 selected genotypes was side-grafted onto a mature cocoa tree with a total of 800–1000 trees used for each trial. The owner-farmers were asked to progressively prune back the root-stock (mother) trees as the side-grafts developed so that ample light and other resources were available for the graft to develop. Because some loss in production was expected as the mother trees were pruned back and before the grafts had developed fully, farmers were given compensation payments. Establishing these early trials was fraught with problems. Lessons learned are outlined below, and these led to some changes when establishing further trials.

Firstly, difficulties were encountered in the logistics and time taken to transport collected grafting material over long distances and sometimes from island to island in Indonesia. Even though the budwood material was kept as fresh as possible by sealing the ends of budsticks with wax and wrapping them in moist banana leaves or foam while they were transported, a high mortality of grafts occurred in the trials largely because it took at least 3 days from collection to grafting at the trial sites. To overcome this we recommend in future trials that farmers and researchers place more emphasis on testing local materials in smaller trials established in the same area. International clones could be propagated in clone gardens under the management of an agricultural research or extension facility and this material could then be easily transported to local testing sites. Other factors also contributed to graft mortality including the skill of the grafters, the condition of the rootstock trees (especially trunk infection with Phytophthora canker), infection of grafts with *O. theobromae* or *P. palmivora,* blight and weather conditions. We recommend exploring other methods of propagation for trial establishment (see below).

Secondly, although the single-tree replicate design is useful where trials are planted on cleared land, in our trials where budstock was side-grafted onto existing cocoa trees, the replicates were widely dispersed over the trial site and were sometimes difficult to locate for evaluation purposes. Later trials set up with plots of six or more trees for each clone replicated in three blocks were much easier to establish accurately and to evaluate. Furthermore, single-tree replicates lack any demonstration value because visiting farmers and other personnel cannot easily view different clones and compare their performance. Plots of six trees or more are much easier to locate and view for demonstration purposes.

Thirdly, we have found that establishing trials on farms requires sensitivity to farmers' expectations and needs, and clarity on what is expected of them from the outset. Although the owner-farmers agreed in principle to the trials and the offered compensation payment, at both trial locations farmers were reluctant to prune back the mother trees to allow grafts to grow and develop. There was a perception that the yield of the existing trees was threatened. In one trial in South Sulawesi, this remained a problem and the grafted clones are yielding very few pods. It transpired that this trial was established on land of neighbouring farmers, not just on the land of the farmer with whom agreements were made, and that, in one case, all the trees belonging to one farmer had been side-grafted. This farmer saw his livelihood as being threatened by the trial. Also, this trial site was subjected to two major flooding events which weakened the cocoa trees, thereby increasing graft mortality and decreasing fruiting. In Southeast Sulawesi, the situation was complicated by the fact that the farm manager, who was the son-in-law of the owner, refused to prune back the rootstock trees, contradicting the agreement we had made with the owner. The owner, one of the wealthier farmers in the area, stepped in and made sure the trial trees were pruned properly. This farmer is particularly encouraging of cocoa research in his area. Also, as he owns a large acreage of farms in Ladongi sub-district, he is risking less than the owner-farmers in South Sulawesi. Our experience suggests that social aspects of the cocoa farming situation need to be considered when proposing on-farm research. It is important to understand who are the main decision-makers. What risks are they taking by allowing the trials on their farms? Who else would be affected by the proposed research (family members, casual labourers)? And what is their level of understanding of the objectives of the research? Gaining information on social considerations is particularly important when entering into agreements with farmers to conduct on-farm research.

Education and Research Combined

Three further trials have been set up, under the coordination of the extension service Dinas Perkebunan, at different locations in Southeast Sulawesi in collaboration with farmer groups formed through SUCCESS Alliance, a US-funded NGO that is involved in fostering participatory education of cocoa smallholders with a focus on farm management and a primary aim of reducing the impact of CPB on smallholders' livelihoods. Some of the promising clones from the earlier ACIAR project trials, in addition to local genotype selections made by the farmers, are being retested in these smaller trials. The farmer groups work together on specified days to help with the grafting, take care of the grafts, assess survival rates of the graft and replace dead grafts. There is a high level of enthusiasm and involvement among the farmers in all the groups in these trials. Often whole families, including older children, become involved, for example by helping with the grafting. It is also planned that the farmer groups help in the collection of basic data when the trials reach the evaluation stage. Through the research trials the farmer groups are adding participatory research to the participatory education method used by SUCCESS Alliance. It is hoped that the participatory element in this research will help to train and encourage farmers to employ the method of local selection and testing of clones themselves and also lead to enhanced dissemination of this approach to other farmers. Such participation also encourages farmers to think independently and experimentally rather than relying on external help.

The ACIAR project has also conducted field workshops for extension, research and quarantine officers and cocoa smallholders. The workshops covered the important pest/disease problems on cocoa in Sulawesi and various management or control options. An important aim of the workshops was to transfer knowledge from the venerable agricultural research institutions in Java, a legacy from colonial times, to Sulawesi, which has become the current centre of cocoa production. In fact, an important priority in the Ministry of Agriculture in Jakarta is to decentralize research and foster knowledge transfer from its older centralized base in Java to regional provinces. The ACIAR workshops thus represented a golden chance for local officers and farmers in Southeast Sulawesi to learn about cocoa pests and diseases and their management from the experienced Java-based cocoa researchers.

Conclusion

The establishment of two (rather than one) large-scale trials for testing selected genotypes has served the ACIAR project well, since due to unforeseen circumstances only one of these has been successful in producing enough pods for evaluation of pest/disease resistance and quality characteristics. Having alternatives sites for such trials not only allows materials to be tested in different environments but also ensures some concrete results are obtained.

The heavy pruning back of mother trees (root stocks) required in the current trials created a very negative perception of the research as it definitely involved destruction of some existing cropping potential. In future research arrangements with farmers we feel it is important that the research is perceived as adding value to the farms. One way to do this would be to bud-graft clones onto seedlings in nurseries and plant these out in gaps where trees have died (from disease, age, storm damage, etc.) in cocoa farms chosen as trial sites. The farmer thus gets a direct advantage from the interplanting of test trees on his or her land and the filling of gaps. Such an approach has other advantages: more plants can be produced from a given quantity of budwood (one bud/seedling, compared to the 2–3 budsticks each with 2–3 buds often used for side-grafting) and graft mortality is lower; also, easier and more uniform nurturing will give more uniform grafted material. For example, in the current work there were problems in the timing of the removal of plastic covers from the grafts.

We learned that it is better to establish many smaller trials with simple designs (6–10 tree plots, three replicates and no more than 10 clones) rather than one or two large trials. The use of many small trials can enhance the extension and demonstration value of the trials by allowing many more farmers to participate. This will be the approach taken in a new ACIAR project that will undertake participatory research with cocoa farmer groups in Sulawesi commencing in early 2007. Overall, our experience with working cooperatively with farmers has been very positive. Farmers are generally enthusiastic and keen to learn about new methods they could apply on their own farms. Farmer groups set up by extension organizations such as SUCCESS Alliance are particularly committed and enthusiastic as a whole. Some farmers involved in the project have already side-grafted portions of their own farms with locally-selected better genotypes. However, caution does need to be preached: it is crucial to warn farmers never to graft significant proportions of their farm with a clone that has not been tested in a proper replicated field trial, as especially the high yield component is very easy to misinterpret from one tree selections. It is crucial to inform farmers about all the advantages of improved planting materials, and ways to make selections and test selected clones, and also about all the problems and work that is involved with doing this well. This is even more important as the level of skills and commitment vary greatly between individual farmers. Also, farmers are understandably wary about research that might risk the production capacity of their own farms. Our experience suggests that research that includes value-adding to their farms and strong educational components are better received in farming communities.

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See: www.cabi.org/datapage.asp?iDocID=476

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Announcements

Are you producing a newsletter or website, holding a meeting, running an organization or rearing a natural enemy that you want biocontrol workers to know about? Send us the details and we will announce it here.

IPPC and BCPC Together in 2007

The International Association for the Plant Protection Sciences (IAPPS) and the British Crop Protection Council (BCPC) are holding the XVI International Plant Protection Congress (IPPC) in association with the BCPC International Conference and Exhibition on 15–18 October 2007 in Glasgow, UK.

Amongst the traditional wide range of topics, a session on 'Efficacy of biological control, using living organisms and natural products' has been allotted a double slot to allow more presentations. Other relevant sessions are 'Assessing and managing the risks posed by invasive alien species', 'Biodiversity in cropping systems' and 'Developments in crop protection, including IPM-strategies, in modern horticulture' (all double sessions) and 'The use of beneficial organisms in plant protection – population level management'.

Novel sessions this year include biofuels and bioenergy, bioterrorism, biosensors, biopharmaceuticals, viruses and phytoplasmas. Specialist sessions include post-harvest-disease control, neonicotinoids, semiochemicals, soyabean rust and mycotoxins. Another new development is sessions covering much wider social issues in recognition that worldwide agriculture is under the spotlight, while a special debate marks the centenary of the birth of Rachel Carson, author of *Silent Spring*.

The deadline for offering papers and posters is 5 April 2007, and this must be done online.

Further information:
BCPC, 7 Omni Business centre, Omega park,
Alton, Hampshire, GU34 2QD, UK.
Email: md@bcpc.org
Web: www.bcpc.org/IPPC2007

Weed Risk Assessment

The 2nd International Workshop on Weed Risk Assessment is being held on 14–15 September 2007, just before EMAPi9 (9th International Conference on the Ecology and Management of Alien Plant Invasions, 17–21 September 2007) in Perth, Western Australia. An expression of interest in the WRA workshop can be registered via the EMAPi9 website (www.congresswest.com.au/emapi9).

The Australia Weed Risk Assessment System has recently been reviewed and the report can be downloaded from:
www.weeds.org.au/docs/Review_of_the_National_Weed_Risk_Assessmt_System_2005.pdf
This document is a good background reading for anyone interested in the process and is recommended reading for potential workshop participants.

Want to Read Wyo-Bio?

Wyo-Bio newsletter gives biocontrol news and views for the US state of Wyoming. The editors are currently updating their mailing list and would like to hear of anyone who would like to receive it (electronically or printed) and is not doing so already – although you can access it online too.

Contact: Fremont County Weed and Pest Control District, 450 North 2nd St., Rm 315, Lander,
WY 82520, USA.
Email: Roz@fcwp.org
Web: www.fcwp.org/wyobio

IPGRI now Bioversity International

The adoption of a new name, Bioversity International (Bioversity in short), for the International Plant Genetic Research Institute (IPGRI) reflects the evolution of the organization and the work it now does. Bioversity remains a research organization dedicated to conserving and using biodiversity, but its scope extends far beyond plant genetic resources, to the conservation of all types of biodiversity, including animal, aquatic and even microbial genetic resources. The new name is also intended to reflect that people are at the centre of all Bioversity does. Along with the new name, there is a new website:

Web: www.bioversityinternational.org/

Bioversity has identified its themes as: Agricultural Ecosystems, Bananas for Livelihoods*, Communities and Livelihoods, Conservation and Use, Economics, Genebanks, Germplasm Collection, Germplasm Documentation, Neglected and Underutilized Species, Nutrition and Policy and Law

*The 'former INIBAP' (International Network for the Improvement of Bananas and Plantain). See:
http://bananas.bioversityinternational.org/

Conference Report

Have you held or attended a meeting that you want other biocontrol workers to know about? Send us a report and we will include it here.

Invertebrate Pathologists Meet in China

The IX International Colloquium on Invertebrate Pathology and Microbial Control, XXXIX Annual Meeting of the Society for Invertebrate Pathology (SIP) and VIII International Conference on *Bacillus thuringiensis* [*Bt*] were held on 27 August – 1 September 2006 in Wuhan, Peoples' Republic of China. The conference was well attended with 285 delegates from 32 different countries, including 110 Chinese delegates most of whom were students from the local university which specializes in *Bt*.

SIP holds annual meetings, alternately in North America and somewhere else in the world to encourage greater participation of non-North American scientists. SIP encourages students, especially the host nations' students, to become involved in the meetings and provides opportunities for students to present oral papers or posters.

One very good session in this year's meeting, with standing room only, dealt with 'Novel approaches for dealing with difficult data'. There were three talks aimed at bioassay data analysis, top reasons why papers have been rejected for publication and dark, dead and dated data relating to industrial secrecy.

There was also a very interesting lecture on the life and work of Edward A. Steinhaus given by Elizabeth Davidson, Arizona State University, USA. Edward Steinhaus set up the first insect pathology laboratory in the USA and taught the first insect pathology course at the University of California, Berkeley in 1945. It was from this laboratory that many of our pioneers in insect pathology came. Edward Steinhaus was one of the founding members of SIP and was the founding editor of the *Journal of Invertebrate Pathology*.

There was a session on new commercial products. Six commercial companies presented their new products and Roy Bateman (Imperial College London, UK) presented the new MycoHarvester Mark V. All of the companies specialized in virus products, *Bt* or plant growth regulators. One company, Andermatt Biocontrol AG, Germany also had two entomopathogenic nematode products under development. No fungal products were presented, which suggests commercial companies still have no strong desire to champion mycopesticides.

Adapted for BNI *from a report by Belinda Luke and Feng Zhang, CABI*