General News

Mammal Biocontrol: the Hunt Continues

Mammal population control is an emotive subject, and scientists searching for effective solutions take this into account. The (particularly urban) public tends to view with disfavour the notion of furry creatures suffering a violent or lingering death, although afflicted landowners may see it rather differently. The public is also very chary about the deliberate introduction of mammalian disease and the possibility of its spread to nontarget species (including humans); species boundaries are no longer confidently regarded as impregnable. Added to that are growing concerns about the environmental impact of poison baits. The challenge for those charged with controlling mammal populations, then, is to come up with solutions that are effective yet meet these constraints.

Elephant (*Loxodonta africana*) control in Africa is a good example. Suffering from the ravages of poaching in the late twentieth century, the elephant became the symbol of threatened wildlife in the continent. Yet effective conservation has led to elephant overpopulation in some areas. Culling, which has long been practised in parts of southern Africa, has also fallen increasingly into disfavour as research on elephant behaviour has confirmed their intelligence and revealed the complex and long-lived familial links within groups. So researchers began to look to other methods. A suitable technique must not only be publicly acceptable and effective, but must also take into account nontarget effects on other species. The elephant has few (and only distantly) related species in Africa (the hyraxes), but control of overabundant marsupials in Australia and pest marsupials New Zealand, for example, has to address this issue.

Germs and Worms

Historically, the most common approach to mammal control has been to increase mortality in the population by culling (e.g. shooting or poison baiting), by spreading disease or by exclusion (e.g. fencing). For introduced mammals, levels of disease may be lower than they are in the home range, its pathogen natural enemies having been left behind. In this case, a 'classical' biological control approach is attractive.

Rabbits (*Oryctolagus cuniculus*) in Australia have long been exposed to diseases introduced from their native Europe in efforts to reduce their devastating impact: myxomatosis was released in the 1950s, and the virus responsible for RHD (rabbit haemorrhagic disease or RCD, rabbit calicivirus disease) escaped from quarantine on Wardang Island (South Australia) in late 1995. More recently RHD reached New Zealand [see *BNI* **19(4)** (December 1998), 99N-101N 'RHD after one year in New Zealand'].

Control of rabbits by RHD in Australia has been patchy. It is notably poorer in temperate areas, and various reasons have been suggested. Recently, analysis of stored blood for antibodies has suggested that some populations may have been exposed to an RHD-like virus before the escape of RHD from Wardang Island. However, as there had been no reports of an RHD-like illness before RHD arrived on the mainland, this mystery virus is assumed to have been non-pathogenic. About 50% of blood samples that had been taken from rabbits before RHD release had antibodies that reacted to an RHD coat protein. Blood samples collected from rabbits in an RHD-free area of central Victoria all had antibodies to the RHD or an RHD-like virus, and nearly half of these survived what would generally be expected to be a fatal dose of RHD. Such antibodies (which can be distinguished from antibodies in a post-RHD survivor) have now been found to be fairly widespread in Australian rabbits, and particularly in populations in the cooler, wetter areas, and this is where RHD-mediated control has been least effective.

RHD in New Zealand has persisted and continued to suppress rabbit populations in many areas. In many of these, it has returned each year, generally infecting older cohorts in spring and then the young of the year in autumn. Reductions of over 90% in numbers have been recorded and generally about 30% of survivors are seropositve [i.e. have antibodies to the disease]. In other areas, the disease has returned every second year, and here rabbit numbers have increased to about half the density before RHD arrived, with about 20% of survivors being seropositive. At a few sites, the disease has not reduced rabbit numbers and has left a high proportion (up to 80%) of survivors across all age cohorts with antibodies to RHD. As in Australia, New Zealand rabbits appear to have a pre-existing calicivirus as evidenced by serological tests (but not yet confirmed by genetic sequencing). However, the evidence to date is that this virus does not impart immunity to RHD, and so is not an explanation for the high survivorship and high prevalence of seropositive rabbits at some sites. There is evidence that seropositive rabbits can retain virus in their tissues. Thus it is possible that infected survivors may remain infectious, and so the possibility exists that the high prevalence across age cohorts noted above might be due to some form of longitudinal transmission of immunity from mother to young rabbits.

The large decline in rabbit numbers has had flow-on effects to other parts of New Zealand ecosystems. Pasture biomass increased at one study site by 77% when rabbits declined by 88%. Brushtail possum (*Trichosurus vulpecula*) and hare (*Lepus europeaus*) numbers have increased, but rabbit predators such as feral ferrets (*Mustela furo*) and feral cats (*Felis catus*) have decreased. However, these changes are not all good news, because New Zealand has not only been overrun with rabbits. The brushtail possum was introduced from Australia to provide for an embryonic fur industry in the late nineteenth century. There are now some 60-70 million possums in New Zealand, which makes them rather more numerous than sheep, and they occur at far greater densities than they do in their home range. The possum is New Zealand's main mammal pest, causing damage estimated at NZ$80-100 million per year, but the biggest threat is that it is the principal wildlife vector of bovine tuberculosis, and if trade barriers were to be imposed on meat and dairy exports, the economic losses would escalate. Traditionally, possums in New Zealand are controlled by the distribution of toxic baits, but economic and environmental concerns have pushed the need for alternative measures to the fore.

Surveys established that the New Zealand possum population has a very limited parasite fauna compared with its Australian counterpart, so the possibility of finding and introducing host-specific natural enemies was explored. A survey of the possums in their Australian home range found a considerably richer parasite fauna, but most parasites (with the exception of the nematode *Adelonema trichosuri*) are not specific to the species. Isolated outbreaks of disease in New Zealand, however, have caused high mortality. The descriptively-named 'wobbly possum disease', caused by a Borna-like virus and an outbreak of enteritis at another site suggest that virulent pathogens may exist. Although it may be possible to look farther afield in both geographic and taxonomic terms, the on-going public and scientific debate about the introduction of RCD to New Zealand may make the introduction of another pathogen of unknown epidemiology fraught with difficulties, and research has moved to focus on fertility control.

Inducing Infertility

Research on reducing breeding success is the control approach seen to have the brightest prospects at present. Three basic techniques are available:

- surgical sterilization
- hormonal contraception
- immunocontraception

Sterilization of both males and females is generally impractical and too expensive except for managing small, easily accessible populations. However, there is an extensive government-funded surgical sterilization programme in place on Kangaroo Island, South Australia, where introduced koalas (*Phascolarctos cinereus*) have multiplied to the extent that they have consumed their natural food source and are facing starvation.

Hormonal contraception using steroid sex hormones to disrupt the oestrus cycle is not species-specific and is also difficult to deliver to a wild population. In some species, at least, there may be undesirable behavioural side-effects to such treatment, as has been demonstrated in African elephants. The success is also mitigated in any animal group where there is a mating hierarchy: if the behaviour of the dominant sterilized male or female is modified then the exercise becomes pointless. On the other hand, targeting the hormonal feedback loops in the hypothalamus-pituitary system that controls gonadal sex hormone production has shown promising results. A team led by Henk Bertschinger (University of Pretoria) used Deslorin, a synthetic analogue of hypothalamic gonadotropin releasing hormone (GnRH), in hormone implants to down-regulate pituitary FSH (follicle stimulating hormone) and LH (luteinizing hormone) release in selected large carnivores such as lions (*Panthera leo*), cheetahs (*Acinonyx jubatus*) and African wild dogs (*Lycaon pictus*). The method was successful in rendering both males and females infertile without behavioural side-effects, and the infertility was reversible. However, Linda Munsen found that progestogen implants in large cats were associated with an increased incidence of tumours of the reproductive tract. Because the Deslorelin is only available as an implant at the moment, remote delivery is not possible. Alternative vehicles are being sought in the USA to allow delivery by means of a dart. There has been much other research on using GnRH as a means of controlling reproduction. An interesting approach is the idea of using GnRH or GnRH analogue – toxin complexes to kill particular classes of cells in the pituitary, and so abolish the secretion of reproductive hormones. This is being researched for dogs and cats in the USA and possums in New Zealand.

Immunocontraception (tricking the immune system into attacking the reproductive process) has a number of advantages, including the important characteristic of being potentially species specific. The technique is based on developing a vaccine to modify the immune response to key targets in the reproductive process: injected with a protein (antigen), the body produces antibodies to it, and subsequently attacks the antigen whenever it appears in the body. Under normal circumstances, the immune system treats its own (and in the case of females, sperm) reproductive proteins as 'self' and therefore 'out of bounds' as antigenic targets. However, if an animal were vaccinated with such a protein so that it appears out of context (in the wrong place), it would develop antibodies to it. The immune system would henceforth treat such a protein as 'foreign' whenever it encountered it, including on sperm or eggs in the reproductive tract, and the animal would be rendered infertile.

Of possible target sites, the complimentary proteins in the sperm head and egg (zona pellucida) coating are ideal candidates, partly because they have some degree of species specificity; a physiological adaptation that serves to preserve species boundaries. This specificity appears to be dependent on oligosaccharide side chains in the zona pellucida proteins and carbohydrate binding properties of the sperm proteins. Interactions between these are necessary for a sperm to penetrate an egg. The most commonly used currently in vaccines, however, are the proteins of the pig zona pellucida (PZP), which are sufficiently close to those of horses, deer and elephant, for example, for the PZP vaccine to elicit an immune response against the zona pellucida proteins in these species. Antibodies are formed to PZP injected into the target animal (because it is different enough for the target animal not to be able to recognize it). When the target animal forms an egg which includes the development of their own zona pellucida proteins, the antibodies will bind to the (target) egg because these are sufficiently similar to those of the pig, hence preventing sperm from penetrating the target animal's newly formed egg.

Any protein that was essential for sperm maturation or progress through either the male or female reproductive tract would be another opportune target. Vaccines to hormones have also been developed. The best known of these is a GnRH vaccine, which will neutralize GnRH in the vaccinated animal, stop FSH and LH release and stop both males and females from breeding. Many carrier versions of GnRH vaccines have been studied and the success rate has been good (80-90%). However, use of hormones as a means of controlling feral or wild populations of animals, albeit successful, may be limited owing to the fact that the product could be passed along the food chain, and this would be likely to occur also with synthetic or recombinant forms of GnRH.

Courses for Horses

The immunocontraceptive method for domesticated and feral animals was pioneered in the USA by Irwin Liu (University of California, Davis). First successes using a vaccine based on PZP were reported in 1989 in domestic and semi-captive wild horses (*Equus* sp.) in California. Results indicated that the vaccine elicited a good immune response among the mares vaccinated, was safe for use in pregnant mares, and did not elicit any short term, adverse side effects. The mares continued to cycle on a normal basis, the contraceptive effect lasted through one breeding season (6-7 months) and was reversible: antibody titres to the vaccine began to decrease to low levels at the end of this time, and when bred again the mares became pregnant. Subsequent studies led by Jay Kirkpatrick (Zoo Montana) on Assateague Island ponies demonstrated that the vaccine could be delivered remotely. This study found some evidence that repeated vaccination (over 5-6 years) could affect ovarian cyclicity, possibly even causing ovarian senescence. However, the Assateague mares administered the yearly vaccines were older mares, and these sometimes undergo spontaneous ovarian senescence, which renders the mares acyclic.

Field implementation of immunocontraception in horses in the USA is primarily directed at wild horses in Nevada, of which there are over 20,000. An estimated one thousand mares have been vaccinated in selected locations considered to be overpopulated, and most of these were freeze branded or tail docked for subsequent identification. Judging from foal counts at the beginning of each foaling season and faecal hormone assays during the pregnancy periods, the vaccination seems to be at least 90% effective using the existing delivery system. Although the effect on the overall Nevada horse population has not been measured, it is clear that in some areas the number of foals born from vaccinated herds has diminished significantly.

Field vaccination campaigns have been hindered because a course of two inoculations (or three for elephants) was needed for effective contraception. Recently, Liu and his colleagues have developed a one-inoculation vaccine that causes failure of conception in horses for at least 11 consecutive months. This relies on a controlled release mechanism developed by Doug Flanagan (University of Iowa, School of Pharmacy). The research team are now working on a one-inoculation vaccine to maintain the contraceptive effect over two consecutive breeding season (20-22 months) and this is currently under experimental trial. However, although extending the period of contraceptive effect will make immunocontraception easier to implement and more effective in wild populations, these studies place considerable emphasis on demonstrating the reversibility of the process, a paramount requirement of an effective contraceptive agent.

Rutting for Nothing

Immunocontraception in white-tailed deer (*Odocoileus virginianus*) is not as well documented as in the horse. It has not undergone the same scientific scrutiny, partly because of the difficulties of maintaining deer under controlled conditions and of obtaining frequent blood samples for measuring the antibody response without stressing the animals. Most experiments with this species have been carried out on the USA's east coast, where the problem of overpopulation is more prevalent. There are some 26 million deer in the USA, and these have serious impacts on crops and the environment (and vehicles!), and are also vectors for a number of human diseases, including Lyme's disease, which has increased in incidence 25-fold in the last 20 years. Amongst a plethora of work on deer in different institutions is research by John Turner (Medical College of Ohio), which has been followed up in a project led by Allen Rutberg (Tufts University). Their results indicated that two doses of PZP vaccine reduced the fawning rate by 70-90% depending on the delivery method. Data showed that deer responded to the vaccine and mounted an immune antibody response (producing immunoglobulins). In addition, it has been demonstrated that the vaccine can be used in pregnant does, and no adverse effects have been found. However, late fawning has been observed among a few vaccinated does, probably because the antibody titres in these animals began to fall before the end of the breeding season. Although very few such cases have been reported, concern has been expressed by animal advocacy groups, and follow up studies will investigate whether late fawning is more common in vaccinated than unvaccinated does.

Monica Stoops (University of California, Davis) is researching the efficacy of immunocontraception in Tule elk (*Cervus elaphus nannodes*) in California. This species provides a good example of the problems that wildlife managers face in containing mammal populations. The Tule elk was once nearly extinct in California. By 1872 only five remained, yet now there are some 3000 in different locations around the state. On Pierce Point in the Point Reyes National Park the herd that began with ten elk imported in 1978 now numbers some 550 head and is overburdening its range. Apart from immunocontraception, possible solutions include chemical sterilization, and relocating or shooting 'surplus' elk. The elk population may harbour a cattle (Johne's) disease so expansion of its range or relocation is unacceptable, and relocation to other reserves would also have an adverse effect on other (invertebrate and plant) species. Public hunting is prohibited in the area, and killing as a method of culling faces strong opposition from advocacy groups. Introducing more (vertebrate) predators is not considered a viable alternative.

Stoops vaccinated 60 female elk in the Point Reyes National Park with formulations of PZP similar to those used in the white-tailed deer studies, and results indicated that a contraceptive effect occurred in approximately 93% of them. Late calving was again observed in a minimal number of inoculated cows, but the numbers were not considered significant by the US National Park Services, which maintains the herd.

One major criticism aimed at immunocontraceptive techniques is the suggestion that males will continue to fight for the right to serve a female past the end of the rut (breeding season) and thus exhaust themselves. This is relevant to species such as deer and elk, where the males fight for the right to service females, although it has not proved a problem in horses. The criticism is based on the fact that vaccinated females will continue to cycle beyond the end of the rut because of their inability to conceive. To date, this has not been shown to have any impact in the deer and elk species studied. At the end of the rut, the dominant males tend to stop fighting, and the existence in the herd of still-cycling and receptive females allows the bachelors to serve females without having to fight for the right to do so.

Pregnant Paws?

If your closest childhood friend was a teddy bear, and you have never had to contend with bears prowling in your backyard, it is hard to imagine that it might ever be necessary to control them. However, in parts of North America bears create a substantial nuisance and danger to the public. Liu's team began trials in April 2000 by vaccinating 20 American black bears (*Ursus americanus*) with PZP. The female bears have since been allowed to breed with males and following hibernation (December until April 2001) the team will determine whether the vaccinated and identified female bears have cubs by their sides… or not!

Jumbo Trial

Field trials of immunocontraception in elephants began in 1996 in the Kruger National Park in South Africa, as part of a collaborative programme between the National Parks Board and the University of Pretoria in South Africa, and the University of Athens, Georgia and ZooMontana in the USA [see *BNI* **18(4)** (December 1997), 104N-105N, 'Immunocontraception in African elephants']. Elephants were located by helicopter, and non-pregnant females were identified by the presence of a calf less than 1 m high. After anaesthetic darting, non-pregnancy was confirmed by ultrasound scan. Elephants were fitted with radio collars, and in a second trial with GPS (global positioning satellite) collars. These allowed them to be monitored and for the initial PZP vaccine to be followed by boosters (at six weeks and six months in a first trial and two and four weeks in a second) which were delivered by drop-out darts from a helicopter. Twelve months after initial vaccination, the elephants were recaptured and re-scanned. The results (reported in *Nature* **407**, 149) showed that of ten free-roaming elephants in the second trial, only two (20%) became pregnant within a year compared to 89% in the control. In addition, a vaccinated elephant in the first trial gave birth to a healthy calf, indicating that immunization had not adversely affected pregnancy. The immunocontraceptive effect was also shown to be reversible and without any behavioural side-effects, which gives it major advantages over surgical and chemical contraception, respectively.

Targeting Pests Down Under

The immunocontraceptive approach is also being developed for three species by the PAC CRC (Pest Animal Control Cooperative Research Centre) in Australia: rabbits, foxes (*Vulpes vulpes*) and mice (*Mus domesticus*), which are all environmental and agricultural pests. RCD has lessened the rabbit problem, at least in hot, arid areas, but it has long been cited as Australia's major agricultural pest, and also as causing (unquantified) damage to native flora and fauna. Mice have a serious impact on cereal production in southern and eastern Australia; the unpredictable outbreaks can cause losses worth millions of dollars, and also social havoc. Foxes cause some losses among lambs, but their main impact is on native fauna.

In a collaborative programme involving Landcare Research, New Zealand and the Cooperative Research Centre for the Conservation and Management of Marsupials in Australia, which includes units at Macquarie University, the University of Newcastle and Queensland Agricultural Biotechnology Centre (QABC) in Queensland and Perth Zoo, the results of experimental trials with a vaccine for possums made from whole sperm were promising, with an 80% reduction in fertility in treated females; trials with PZP vaccine gave 75% reduction. Research is continuing to improve the efficacy of this vaccine by isolating the proteins responsible for the immune response (and the genes expressing them), and is looking into the possibility of using proteins involved in other parts of the reproductive cycle. Experiments with possums in captivity have shown 70-75% reductions in fertility with vaccines based on two zona pellucida (ZP2 and ZP3) proteins. In Australia similar work is being done on wallabies and kangaroos (*Macropus* spp.), which in certain areas of the country pose a highly significant threat both in competition of rangelands and crop damage.

So the prospects of a practical tool for some species are promising, but how will this affect the populations in practice? If lowering breeding success is to have an impact on population numbers, the birth rate must be reduced to match the minimum (density-independent) mortality rate. Modelling studies suggest that 60-70% of females need to be made infertile to have an impact, but if only males are targeted, almost all of them would have to be rendered sterile to have a sustained population effect. This makes male contraception impractical as a sole population control tool, but the necessary levels of infertility have been achieved, if only just, in, for example, possums. Improving the 'hit' rate of female immunization is therefore a priority, and this can be partly addressed by improving the delivery system. Targeting both males and females in a population may also be beneficial.

Safe Delivery

A crucial feature of biocontrol programmes is the development of an effective release system. This is particularly so for immunocontraception. In the trial in South Africa, the elephants were darted with anaesthetic, then vaccinated and fitted with tracking collars. It is not unreasonable to suppose that this method could be simplified (the immobilizing and tracking phases would not be necessary) for more widespread application in elephants... but not for the 30-odd million (female) possums in New Zealand. A rather more automated delivery system is needed. One possibility is non-toxic baits (i.e. an oral contraceptive), but an approach currently exciting interest is self-disseminating transmission. The idea was pioneered in the early 1990s by Hugh Tyndale-Biscoe, who worked for CSIRO (Commonwealth Scientific and Industrial Research Organisation) Wildlife and Ecology and was at the time the first Director of the Vertebrate Biocontrol CRC (which has now evolved into the Pest Animal Control CRC).

The method is based on inserting the antigen into the DNA of a non-virulent viral, bacterial or parasitic vector specific to the target species. When an animal becomes infected, the protein gene is expressed, and the animal's immune system produces antibodies against it, as outlined above. In Australia, for example, scientists have shown that the vaccine inserted into a non-virulent strain of the myxoma virus can give effective contraception in rabbits for up to three months. For captive or isolated populations, a 'crippled' agent (i.e. one unable to reproduce itself) would be used to infect animals and block reproduction, but it would not spread further. However, for widespread and inaccessible populations, an infectious agent could greatly enhance dissemination of the vaccine. This, though, would have application in limited instances. In Australia the possible impact on nontargets would preclude its use in marsupial management, but it might be appropriate in New Zealand where eradication of the brush-tailed possum is desirable. But even then, risks of escape from New Zealand would have to be considered. Thus, the risks of using a disseminating vector would need careful evaluation. Henk Bertschinger points out that although the PZP vaccines are not species specific, once delivered via a vaccine they could be inactivated if eaten, so long as the vaccine is formulated with this in mind. They are thus, in native form, safe within the food chain. The danger of virally vectored vaccine is that it may not be safe within the food chain as viruses can and do undergo mutation. He points out that in Africa, with its vast diversity of species, virally or bacterially vectored DNA vaccination would be out of the question; he argues that there is too great a risk that this would mutate and affect nontarget species.

Baits are still favoured as a method of delivery for mice and foxes. This is in part because suitable pathogens for delivery have yet to be found for foxes, although there is a candidate for mice, but also because the registration procedure is likely to be simpler, and the public are expected to accept baits more easily than an unknown pathogen carrier. In contrast, the epidemiology of the rabbit myxoma virus is well researched and understood, it is now endemic in Australia, and there are no closely related native species. It is also relatively easy to incorporate the vaccine protein gene into it. However, field results with naturally occurring myxoma virus strains have suggested that competition between strains of the virus may affect the field transmission of a vaccine.

Baiting may remain the method of choice in some cases, and there is interest in increasing the efficiency of this delivery system. All Australian marsupial mammals currently targeted are plant feeders, and baits need to be plant based. Marsupial CRC scientists are investigating the possibility of inserting a marsupial antigen into easily grown palatable plants, such as maize or carrots, which would then be formulated into baits. Maize is particularly promising, partly because its genetic manipulation is fairly tractable and the technology well-established, but also because it can be grown as a sterile hybrid and it has no close wild relatives in Australia.

For larger animals, 'darting' may remain the preferred solution over baiting (as it reduces the likelihood of effects on non-target species) and over pathogen-containing vaccines for controlling patchy populations. In the USA 'biobullets', biodegradable hydroxypropyl cellulose and calcium carbonate darts, have been developed for delivery of PZP vaccines to white-tailed deer.

Not a Silver Bullet

Reducing breeding success is not expected to solve all of the mammal problems by itself, but integrated with other biological and conventional chemical measures, it will be a useful tool for population management, and may allow local, or even area-wide, eradication in some cases. All modelling in this field has suggested that fertility control will have to be used in conjunction with conventional methods, even if it just means a large cull or poisoning programme to reduce the initial population size followed by fertility control.

The development of immunocontraception is at an early stage, and although trials of marsupial vaccines, for instance, may begin within the next five years, it may be 10-15 years before vaccines and delivery systems are perfected for all of the current target species. There are many hurdles still to be overcome, not least of which is dealing with the (differing) risks involved in the new techniques, and in the mode of delivery. For bait delivery, species specificity and biodegradability are key, while for a vaccine vector, the specificity of the vaccine and the specificity of the mode of transmission are both critical. If the agent of transmission is a genetically modified, albeit non virulent, pathogen, then public and scientific concerns relating to the release of genetically modified organisms into the environment need to be addressed. So do public worries about spreading what might sound suspiciously like a disease – worries familiar to classical biological control practitioners working with alien pathogens.

Given the antipathy that can be raised, it is wise to involve all stakeholders in decision making on wildlife problems, and where this has been done it has had very beneficial consequences. Irwin Liu suggests that the most significant contribution of imunocontraception so far in the USA has been in reducing the hostility between government agencies (who have jurisdiction over most of the wild animal populations) and advocacy groups. Developments in fertility control could lead to effective methods for humane management of mammal populations, with minimal cost and human intervention, that are acceptable to most parties.

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Metarhizium: Changing Locust Control

We have many times covered progress in the development of biopesticides based on *Metarhizium anisopliae* var. *acridum* for locust control. Now there are formulations ready for use, and at a time when locust outbreaks in many parts of the world are hitting the headlines. However, it is not only the 'green' credentials of the biopesticides that make them an exciting new tool, but the promise they bring of new strategies for controlling this most infamous of insect pests. The biopesticides have a slow knockdown rate (up to 10 days) compared to conventional insecticides, but field trials have shown them to have a more persistent effect, and this makes them ideal for use in breeding areas. In addition, their environmental safety means that they can be used in conservation areas where locusts were previously safe from the sprayers.

Locusts Face Operation

The biopesticide Green Guard™ developed by CSIRO (Commonwealth Scientific and Industrial Research Organisation) and manufactured by Seed Grain and Biotechnology (SGB), Albury is to be used operationally this year as Australia faces its largest-ever plague of locusts. According to the Australian Plague Locust Commission (APLC), for the first time in living memory locusts threaten agricultural production on both sides of the continent in the same year. Western Australia is facing the largest plague ever, threatening its wheat belt and other agricultural areas. South Australia is facing the largest since 1955, and New South Wales and Victoria the largest in ten years. Graeme Hamilton, head of APLC, says that an intensive control effort will be needed to avert major crop and pasture damage.

Months of planning a defence strategy with state agricultural departments and farmer groups will be put to the test. A key element of this will be the *Metarhizium*-based Green Guard™, which has been given a special permit by the National Registration Authority for Agricultural and Veterinary Chemicals (NRA) to be used in widespread operational trials. It is applied under the direction of APLC as an aerial spray of dry spores suspended in oil, with locusts infected either by direct contact or by picking up spores from vegetation. The spores penetrate the body and kill the locusts in the second week of infection. This is a major boost in the APLC's armoury, and a surprise for the locusts, as it enables the commission to spray in conservation areas, on organic farms and in sensitive environmental places such as wetlands and river banks where chemical pesticides cannot be used. The biopesticide, which is based on a native *Metarhizium* strain originally collected from the spur-throated locust (*Austracris guttulosa*) will also be used in trials in Western Australia (WA) for the first time by the WA Agriculture Protection Board. Green Guard™ is not available to farmers and landholders, however, as not all the data required for registration by the NRA has been compiled. CSIRO anticipates that this registration will take place within the next twelve months. The operational trials permitted this year will be an important element in the registration process.

Head of CSIRO Entomology, Jim Cullen is delighted with that the promise shown by *Metarhizium* is bearing fruit in such an important application as locust control. Trials last year showed high locust mortality at one fifth of the anticipated dose, and at this low dose the cost of using the biopesticide is competitive in price with chemical insecticides.

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Buying into Biopesticides

Meanwhile in Niger, stakeholders involved in the development and deployment of Green Muscle™ are celebrating the first commercial release of the biopesticide in what is believed to be the largest aerial spraying of a biopesticide ever conducted in Africa. Early reports indicate that the biopesticide provides complete control for up to three times longer than chemical insecticides currently used, making it less expensive and environmentally safer for farmers.

The commercial release of Green Muscle™, conducted in August 2000, targeted a 2000 ha area in Tahoua Province. Tahoua, an area of fertile agricultural valleys south of the Sahara desert, was devastated by locusts four times between 1986 and 1989 and again in 1992-93. The government of Niger, which is the first African government to integrate the biopesticide into its pest control programme, plans to introduce biopesticides to 300,000 ha of agricultural land currently treated with chemicals. The per unit cost of using the biopesticide (less than US$10/ha) is approximately the same as conventional pesticides, but its overall usage cost is about one-third less because the fungus requires only one application per season.

The fungus strain currently used by scientists is indigenous to Africa, but strains from various origins can be used to make localized formulations for different regions (as indeed CSIRO has done). Development of Green Muscle™ was an inter-disciplinary effort, involving identification of an appropriate strain of the fungus, and development of methods for its mass production and application. The isolate used for Green Muscle™ was selected from more than 160 strains of fungi and other locust pathogens. Mass produced fungal spores are added to an oil-based carrier for spraying, a process approved by the Food and Agriculture Organization of the UN (FAO) in 1997. Biological Control Products of Durban, South Africa was the first company to receive a license to produce Green Muscle™ and negotiations are currently underway with other manufacturers in the private sector.

Jürgen Langewald (International Institute of Tropical Agriculture, IITA), project leader of LUBILOSA (LUtte BIologique contre les LOcustes et les Sauteriaux) which developed Green Muscle™, points out that because of the immense size and range of locust swarms, there is little that individual farmers can do when locusts strike, so it is up to governments and international organizations to take the lead. He is enthusiastic about the potential of Green Muscle™ for controlling locusts in their breeding grounds. Areas around the Red Sea could be treated each year with the biopesticide to catch young locusts before they are mature enough to fly and become a threat to farmers' fields. According to Langewald, the cost of treating these areas would amount to US$15 million annually, a fraction of the $500 million that might be needed for all-out chemical spraying after the locusts have swarmed. He points out that while it is easier to raise money after a crisis has occurred, a programme based on prevention through biological control will better serve both people and the environment. According to the government of Luxembourg, the major funder of Niger's grasshopper and locust control programmes for many years, the August sprays have already helped to shift the thinking of Niger's pest control establishment – a direct result of the LUBILOSA programme.

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Read All About It!

For more about the history of the LUBILOSA story, a new publication* traces the development and commercialization of biologically based technologies for sustainable locust control. A public-private partnership involved a group of governmental aid agencies who provided US$13 million for an international inter-institutional research and development programme into the problem of locust control for the developing world. The programme showed that public-private partnerships can work, and that public and private perceptions about intellectual property rights can be reconciled. The result is Green Muscle™.

*Dent, D (2000) Intellectual property rights, partnerships and the LUBILOSA Story. Egham, UK; CABI Bioscience.
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Dr M. A. Ghani: His Contributions to Biological Control

Over a span of almost fifty years Dr Mohammad Abdul Ghani, until his retirement in 1980, led a distinguished career in entomology and biological control.

Born on 10 June 1915 at Ludhiana (Punjab), India he completed his early education at Arya High School before attending Punjab Agricultural College, Lyallpur where he obtained both his B.Sc. and M.Sc. degrees, graduating in 1945 at the top of his class. On the basis of his academic excellence he was awarded a scholarship by the Government of Punjab to pursue graduate studies in the USA. He completed his Ph.D. at the University of Massachusetts in Amherst in 1950.

His entomological career started in 1934 when he was appointed Research Assistant in the Entomology Section of the Punjab Agricultural College and Research Institute, Lyallpur (now the University of Agriculture, Faisalabad). On his return from the USA he rejoined the Entomology Department of the University of Punjab and was promoted to Associate Professor, University of Agriculture in April 1955. In June 1955 he was appointed Plant Protection Entomologist, Plant Protection Department, Government of Pakistan. Two years later in 1957 he joined the Commonwealth Institute of Biological Control (CIBC) as Entomologist-in-Charge of the newly formed Pakistan Station at Rawalpindi, a position he held until his retirement in 1980.

From its inception Dr Ghani was deeply involved in the planning and construction of the CIBC Pakistan Station which was funded largely by Colombo Plan Funds provided by Canada. A tireless worker and excellent organizer, the project load of the station grew rapidly requiring the development of a chain of up to eight substations to service a broad array of biological control and integrated pest management (IPM) activities. In addition to financial assistance from Canada, the Pakistan Government and the Commonwealth Agricultural Bureaux, United States PL480 projects proved a major source of funding during most of the period that Dr Ghani spent with CIBC. Once the Pakistan Station became fully functional between 12 and 27 major projects, many of them of several years duration, were being carried out at any one time. During the 23 years he served CIBC, he undertook personally, or directed, more than one hundred projects in biological control and IPM. Investigations were undertaken for, and/or natural enemies were shipped to, more than 30 countries. These led to the establishment of a number of natural enemies and to partial or complete biological control of the target insect or weed pest. The most outstanding of these resulted from the introduction from Pakistan to New Zealand of the braconid *Apanteles* (= *Cotesia*) *ruficrus* for the control of the cosmopolitan armyworm *Mythimna separata*. Establishment of the parasite and its impact on the host quickly resulted in a dramatic reduction of pesticide use and increase in crop yields. The estimated annual monetary benefits range from NZ$4.5 million to NZ$10 million[1].

To develop and sustain this heavy workload Dr Ghani recruited a team of young Pakistani entomologists and other scientists: several of these, under his guidance, completed advanced degrees while working at the Station and later accepted positions of national or international prominence in biological control and IPM. Dr Ghani also acted as external examiner for a number of M.Sc. and Ph.D. students at three universities in Pakistan, and sat on various university committees. He actively promoted and encouraged university courses in biological control and IPM and published more than 80 papers in national and international journals.

In addition to his duties at the Station Dr Ghani travelled abroad extensively and visited most of the continents in connection with professional activities, at times under arduous conditions. During 1961 he spent two months in Indonesia collecting sugarcane borer parasites for Mauritius. In addition to enduring great personal discomfort he was forced to part with his wrist watch and several other personal items as inducement to permit him to continue his investigations and to ensure that the numerous shipments of parasites to Mauritius, Trinidad and India were dispatched expeditiously.

In recognition of his services and dedication to his profession several honours were conferred on Dr Ghani. These included the Gold Medal in Biological Sciences for 1970 by the Pakistan Academy of Sciences, Gold Medal by the US Department of Agriculture for excellence of research on PL-480 projects in 1985, and 'Tamgha-e-Quaid-I-Azam' by the Government of Pakistan in 1965. He was a member and fellow of several learned societies including the Pakistan Academy of Sciences and the Royal Entomological Society of London.

Always a very modest and courteous man Dr Ghani, after his retirement from CIBC in 1980, lived quietly with his family in Faisalabad, and later during a protracted illness in Islamabad where he died on 6 April 2000. Dr Ghani leaves behind his wife, three sons, one daughter and ten grandchildren.

[1]Hill, M.G.; Allan, D.J. (1989) *Mythimna separata* (Walker), cosmopolitan armyworm (Lepidoptera: Noctuidae). *In*: Cameron, P.J.; Hill, R.L; Bain, J.; Thomas, W.P. (*eds*) A review of biological control of invertebrate pests and weeds in New Zealand 1874-1987. CIBC Technical Communication No. 10. Wallingford, UK; CAB International, 424 pp.

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Dieter Schroeder Bows Out

After more than 40 years in the service of biological control, Dieter Schroeder retired in September 2000. For almost all of this period he was based at the CABI Bioscience Centre Switzerland (formerly the European Station of the Commonwealth Institute of Biological Control – CIBC, then the International Institute of Biological Control – IIBC). He was Centre Director for the last four years, a period especially noteworthy for the construction of an extension to the centre building that increased the accommodation by 50%. Matthew Cock, formerly IIBC Deputy Director of Operations and CABI Bioscience Weed Biological Control Programme Leader takes over as Centre Director of the Switzerland Centre in Delémont, with its active and committed staff and strong research programme.

Dieter was born in Germany in 1935 and passed his youth in what was called East Germany after 1945. His wish to study biology could not be realised in the circumstances, but since he was trained as a lumberjack he was ordered to study forestry. Three months before his final examinations he was forced to leave East Germany and finished his studies in Göttingen, West Germany. Instead of becoming a forest district officer, he accepted an offer to become junior entomologist at the European Station of CIBC, working on biological control of forest pests, such as larch sawfly, pine sawflies, balsam woolly aphid and pine shoot moth. The latter species became the subject of his PhD thesis in 1962. In 1969 he joined Helmut Zwölfer in his work on biological control of invasive weeds, including amongst others leafy spurge, thistles and St. John's wort, and he took over the Delémont weed section in 1973, when Helmut Zwölfer left.

Before concentrating on weed biocontrol, he spent a year in Ghana, running the CIBC Ghana Sub-station, and working on pests of corn, rice, cocoa, and water weeds. Following his return to Switzerland in late 1970, he worked in close cooperation with Peter Harris in Canada, mainly on knapweeds and leafy spurge, but also on a number of other species, such as mullein, bladder campion, sow-thistle, toadflax and dandelion. Over the past twenty years, biological weed biocontrol developed into a major component of the work of the centre in Delémont with six research scientists and a varying number of Diploma and PhD students. Dieter has written or co-authored well over 50 publications that have greatly stimulated ecological thinking in biological control.

Quite early on Dieter established close cooperation with the USDA-ARS (US Department of Agriculture – Agricultural Research Service) and the Australian CSIRO (Commonwealth Scientific and Industrial Research Organization) European weed biocontrol laboratories, and initiated with Paul Dunn annual meetings of the three groups to exchange information, and to avoid duplication of work. Supported by Peter Harris, Dieter put much effort into encouraging Canadian and US scientists and sponsors to join forces and form consortia to enhance support and progress in biological control of invasive weeds. There are now several such consortia coordinating the biological control programme against different weed targets. In addition to his Europe-based weed work, Dieter travelled the world, participating in international training courses in Trinidad, India, Pakistan, and Kenya, and acted as a consultant in North America, Africa, Chile and the Solomon Islands.

Dieter's contribution to weed biological control was recognised publicly by professional colleagues last year when he was an honouree of the Xth International Symposium on Weed Biological Control at Bozeman, along with Peter Harris and Lloyd Andres. This year his retirement was marked more informally at a party held at the CABI Bioscience Switzerland Centre in August. The staff and students of the Centre, together with collaborators and former staff from Switzerland, Germany, Canada and the USDA EBCL (European Biological Control Laboratory) Montpellier, marked the occasion with one of the Centre's traditional barbecues, and the presentation of gifts and mementos, including a book of personal memories, stories and pictures sent by more than 50 colleagues from around the World… and the Centre's last ash tray! Proceedings were further enlivened with the first public performance of 'Dieter's Song' (set to the tune of 'Those Were the Days'), a display of salsa dancing by students of the Centre and an exhibition of juggling by a distinguished guest whilst he gave a commentary in three languages. Dieter will be remembered by those who worked with him for his enthusiasm, strong opinions, and certainly his humour and many jokes and stories. We all wish Dieter a long and fulfilling retirement, which, judging by his plans, will be no less busy than his career.

By: Matthew Cock and André Gassmann (CABI Bioscience Centre Switzerland) and Heinz Müller-Shärer (University of Fribourg)

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New Committee for IOBC

IOBC, the International Organisation for Biological Control of Noxious Animals and Plants, has announced its new global executive committee for 2000-2004. The president is Lester E. Ehler (University of California at Davis, USA), and Joop van Lenteren (University of Wageningen, Netherlands) and Stephan Pruszynski (Plant Protection Institute, Poznan, Poland) are vice-presidents. André Gassmann (CABI Bioscience Centre Switzerland) becomes secretary-general, and Fritz Polesny (Institute for Phytomedicine, Vienna, Austria) is treasurer.

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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.

Rational Pesticide Use: an Alternative Escape from the Treadmill?

IPM is a strategy that aims to optimize all available techniques in order to maintain pest populations at levels below those causing economic injury. The concepts behind IPM have evolved since their beginnings in the late 1950s. It is generally agreed that one of the primary objectives is reduced reliance on (especially toxic, broad-spectrum) pesticides and some believe that IPM may (or should) result in reduction or removal of chemical pesticide use. In practice, however, the pesticide industry has remained a profitable (although maturing) business (Figure 1). This indicates that many farmers continue to believe that pesticides are necessary to prevent significant losses in many crops (the largest market), besides which, insecticides continue to be used for control of disease vectors and nuisance pests. Here, I examine some of the reasons for the continued prevalence of pesticides in pest management, and suggest how a more reasoned approach, which accepts the value of pesticides but concentrates on delivering the active ingredients (a.i.s) more effectively, can make a real contribution to pesticide reduction.

Changes in pesticide use are not as easy to quantify as it might seem. During the final two decades of the 20th century, the total value of pesticide sales increased some 2.5 times. This statistic can be misleading because it does not take factors such as inflation into consideration, but average trade weighted growth has been some 1.6% annually. Figures for tonnes of pesticide produced are hardly more useful, since modern pesticides are used at substantially lower rates of application. It would be useful to express sales in terms of hectare dosages, but such data are available only very rarely (a notable exception being in Denmark, see: <http://www.inet.uni2.dk/~iaotb/top20.htm>). Figure 1 reveals some other significant trends including (a) an increase in the importance of herbicides (mostly at the expense of insecticides) and (b) the present relative unimportance of genetically modified crops (in contrast to their news-worthiness). Figure 2 shows how the regional distribution of pesticide sales has varied over last 20 years. Although Europe and North America continue to account for the largest portion of the market (some 56% combined), there has been nearly a 10% increase in the market share to 36% for Asia and South America (partly in place of eastern Europe), and pesticide use patterns in these regions therefore deserve special attention.

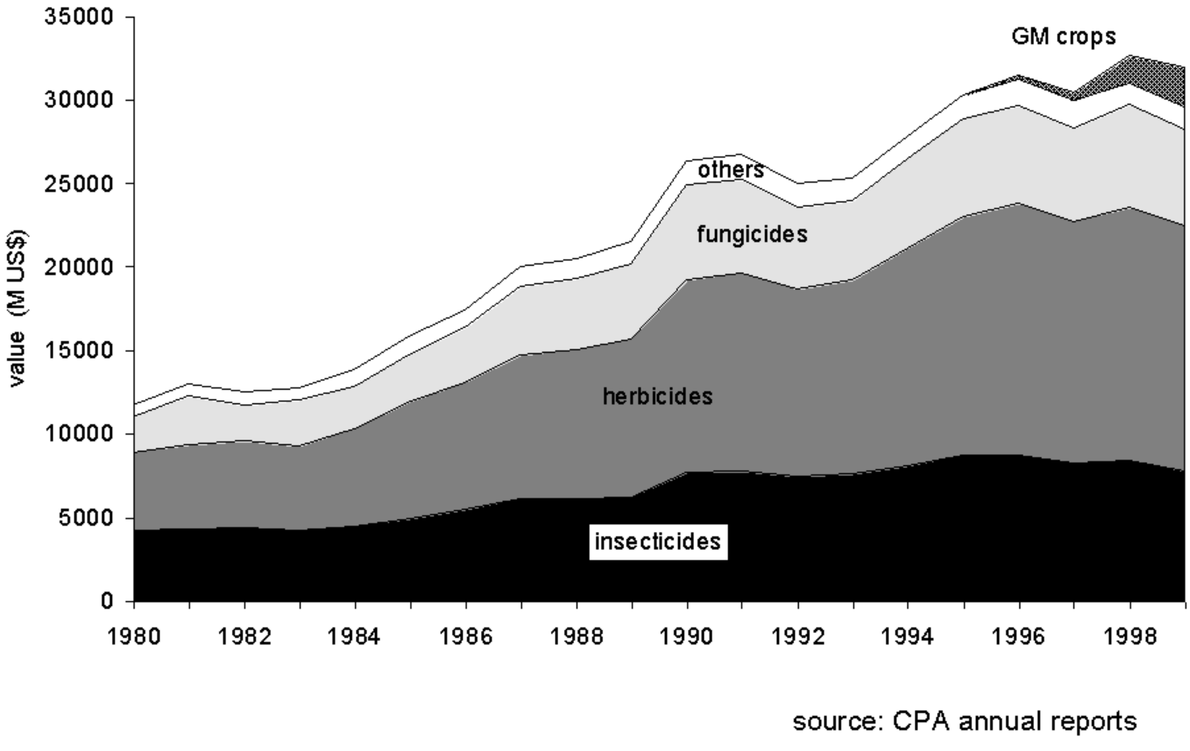

Figure 1. Worldwide pesticide (crop protection) markets in the final two decades of the 20th century (data compiled from British Crop Protection Association Annual Reports).

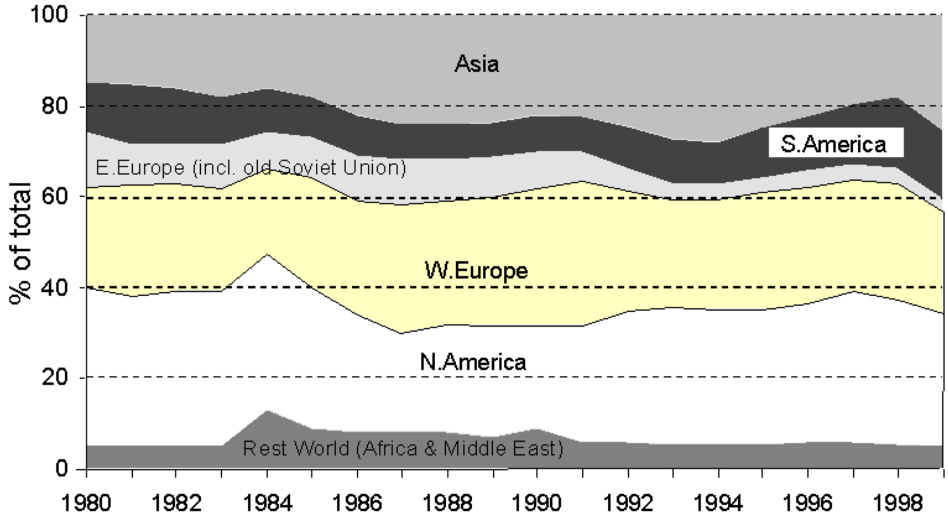

Figure 2. Regional trends in pesticide use (data source as Figure 1).

The term rational pesticide use (RPU) was coined in the title of a book by Brent & Atkin in 1987[1]; it can be defined as a focused sub-set of IPM, which attempts to mitigate the adverse effects of pesticide use by improvements in the selectivity of the products themselves and the precision of their application in both space and time. The benefits are maximized with a combination of all three, and the potential benefits include: reduction of costs (for both pesticides and labour), improved safety (especially with insecticides) and reduced environmental impact (through more efficient use of sprays and the use of specific agents).

On a world-wide scale, farmers are likely to be most interested in cost savings, but this will be especially important in the poorest communities. Developing countries presently account for approximately 25% of global agricultural sales values and this proportion is projected to rise. However, not only do agricultural inputs contribute to the debt cycle, but with limited access to protective clothing and medical facilities, cases of pesticide poisoning are more common in developing countries, and have a greater impact on poorer farmers.

Concepts similar to RPU have been promoted elsewhere: all attempt to achieve sustainable agriculture, with a low environmental impact, through a combination of appropriate technologies, but not necessarily excluding the use of pesticides. Examples include: *lutte raisonée* (supervized control) promoted by the FARRE project in France; 'green agriculture' promoted by the Chinese Academy of Agricultural Sciences (together with 'white agriculture', that focuses on the use of microbial agents); and 'clean production' in Vietnam (where management of pesticides is combined with more careful use of human waste as a fertilizer).

It is beyond the scope of this article to review the many facets of RPU, but it highlights some of the ways in which it can benefit IPM, concentrating in particular on the potential of controlled droplet application (CDA).

Slow Growth of Specifics

There has been a significant trend towards the development of molecules and formulations with lower mammalian toxicity by the major agrochemical companies over the last 30 years. However, with huge development costs, the companies have been under pressure to develop pesticides which have a broad spectrum and thus a wide market, for example neo-nicotinoids and pyrethroids. More specific compounds (even aphicides) by definition occupy smaller proportions of the pesticide market and therefore promise a smaller potential return on research investment. In addition, toxic chemicals (especially organophosphorus compounds such as methamidaphos and monocrotophos) are still widely manufactured and marketed, and alarmingly are still available to unprotected smallholders in some developing countries. More specific compounds are available (e.g. insect growth regulators, fermentation products such as spinosad, and biopesticides) but they tend only to fill 'niches' in the pesticide market. Although the need for more specific insecticides is often identified in farmer field schools and by scientists, commercial pressures mean that this does not translate easily to the market place.

Paradoxically therefore, one of the costs of heightened regulatory pressure has been an increased incentive to develop broad-spectrum products that have a large market value, thus possibly increasing the impact of pesticides on nontarget organisms and the environment. The use of broad-spectrum molecules is known to aggravate problems such as pesticide-induced resurgence of relatively unimportant insects and mites. One of best-known examples of this is brown planthopper (*Nilaparvata lugens*) in tropical rice, which flares-up almost predictably after applications of many pyrethroids. With appropriate cultivation of this crop, it is most straightforward to discourage insecticide use all together, although migratory pests may remain a problem. However, the use of herbicides (for directly seeded rice) and fungicides (against diseases such as sheath blight) is increasing in some countries, and RPU may be able to provide the more complex solutions needed for effective rice protection in such situations.

Between Two Camps

Although good IPM practice comprises the best combination of techniques to manage pests, opinions about the emphasis placed on the various components have become polarized over the last 30 years. Most authorities agree that successful pest management requires a holistic approach that includes cultivation of the crop itself; thus some sections in the Food and Agriculture Organization of the UN (FAO) and other workers with a background in biological control refer to 'integrated production and pest management' (IPPM). On the other hand, the Global Crop Protection Forum, representing the major companies wishing to develop both pesticides and genetically modified crops, promotes the term 'integrated crop management' (ICM). Unfortunately the protagonists of the two approaches rarely talk to one another, even though there are many similarities between the concepts (their main disagreements are often over essentially socio-economic matters).

Faced with the sustained importance of pesticides, and the absence of specific compounds, RPU provides a means of minimizing use and impact, and this fills a niche in IPM left by pesticide-excluding approaches, yet always attempts to minimize their impact. Scientists, practitioners and policy makers involved in IPM have tended to view any activity associated with pesticides as belonging to the pesticide companies (and preferably to be avoided). In turn the chemical companies (which often provide farmers with most of their information on products) are unlikely to develop or promote techniques that reduce pesticide use (and hence sales). The result is a lack of information and technological development for improving the selection and use of pesticides in a way that will lead to real reductions in use.

Applying Less More Precisely

It is rarely appreciated just how inefficient existing application practices are. In 1977, Graham Bryce pointed out that most conventional insecticide applications as foliar sprays were <0.05% efficient, although (exceptionally) this might reach 6% efficiency for aerial sprays to locust swarms, and herbicide sprays on grass weeds might reach 30% efficiency. Thus, even in the best case, 70% of the pesticide is wasted. Improved application techniques received much attention and extensive research in the 1970s and 80s, but then went out of favour, partly when the commercial potential of genetically modified crops became apparent. With the increased use of herbicides, application research in the 1990s often focused on control of spray drift (not necessarily accompanied by gains in efficiency: see below). Most recently, the concept of 'precision spraying' has received attention, which is linked to sophisticated crop monitoring techniques controlled by global positioning systems, and applications are targeted to patches of pests (usually weeds). However, precision spraying has been developed for European and North American conditions and essentially relies on switching conventional atomizers on and off; it does not necessarily address the fundamental inefficiencies resulting from the random nature of liquid break-up by hydraulic pressure.

The concept of controlled droplet application (CDA) is perhaps the ultimate in precision spraying, but it has been disappointingly limited to niche markets. It attempts to maximize dose transfer to a given pest target by the creation of appropriately sized, uniform pesticidal droplets (within practical engineering limits). A number of studies have shown smaller (<150µm) droplets to be more effective for control of arthropod pests and plant diseases than larger ones. Optimization of herbicide use involves a compromise between minimizing drift (by minimizing the volume of spray with droplet sizes of <100µm) but also ensuring that droplets are not so large that they bounce off foliage (an effect that may start to occur if they are >200µm). For a given biological target it is usually possible to estimate the approximate limits of an optimum size band for spray droplets, but more research with individual cases is always desirable. In addition, by targeting sprays better and reducing their number, it may be possible to prolong the life of a.i.s by delaying the development of pest resistance.

CDA uses minimal quantities of a pesticide to maximum effect by improving timing and spatial application, with the additional benefits of reducing off-target contamination and improving work rates. By creating narrow droplet spectra, ultra-low volume (ULV) or very low volume (VLV) application rates can achieve similar (sometimes better) biological results than conventional (hydraulic atomizer) application. Perhaps one of the greatest practical advantages of these low volume techniques involves their capacity to improve work rates; for example, one hectare of cotton might take more than 11 hours to spray at 200 litres/ha (with a conventional knapsack sprayer), but only 4 hours at 10 litres/ha (VLV) or one hour at one litre/ha (ULV). Such improvements in work rate not only reduce labour costs, but also improve timeliness of application in response to monitoring techniques; thus CDA is a very good example of RPU technology.

Early CDA initiatives had only limited success, probably due to a combination of unreliable equipment, insufficient promotion and a perceived need for special formulations. The cause was not helped when the inventor of modern rotary atomizers, Edward Bals, suggested in 1969 that besides ULV rates of application, CDA might achieve 'ultra-low dosages'. This idea was obviously an anathema to many chemical companies since it could threaten product sales. However early in the 1980s, ICI (now Zeneca, shortly to become Syngenta) recognised, with the development 'Electrodyn' technology, that profitability was not necessarily linked to tonnes of a.i. sold. It recognised that added value might be achieved by incorporating the product in a proprietary delivery system for smallholder farmers. Electrical forces were used to break up the oil-based formulation into very small, very evenly-sized droplets, then to carry and distribute them onto the plant surface. By combining the bottle, formulation and nozzle in a closed, disposable system (the 'Bozzle'), operator exposure and application errors could dramatically be reduced by eliminating the mixing and measuring stages and simplifying calibration.

Although technically brilliant, electrostatic spraying in general has failed to make a commercial impact. In the case of the Electrodyn, farmers in some areas were unwilling to commit themselves to the products of just one company, and there has been increased regulatory pressure against the solvents used in formulations (a critical component in the 'Bozzle' system). However the rotary atomizer companies survive, and many of the technical problems that constrained widespread adoption of CDA in the early days have now been resolved. With the current heightened awareness of environmental, social and toxicological issues associated with pesticides there is perhaps an opportunity to 'rediscover' some of these latent technologies. Provided relatively non hazardous a.i.s are used, CDA spraying, together with other RPU techniques such as banding, baiting, specific granule placement and weed wiping might even ameliorate the currently poor image of pesticides. However, in many circles drift is seen as one of the major problems that pesticide application research has to address.

Drifting Off-Course

Recent changes in policy and practice (especially in Europe and North America) have focused on reduction of spray drift (an issue that has always been important with herbicides). The most common solution has been to develop nozzles that increase droplet size spectra, although this shift takes spray droplet size out of the range demonstrated to be effective for pesticide application. In 1974 Himel distinguished between 'exodrift' (transfer of spray out of the target area) and 'endodrift', where the droplets fall into the target area but the a.i. does not reach the biological target. Endodrift is volumetrically more significant and may therefore cause greater ecological contamination (e.g. where chemical pesticides pollute ground water). Unfortunately, the policy and regulatory changes that encourage the use of larger droplet sizes in ordinary spray nozzles risk reducing exodrift at the expense of an increase in endodrift. With spray application, it is important to focus on maximizing pesticide delivery to the target, rather than just minimizing drift. Concepts such as controlled drift spraying with narrow droplet size spectra are often critical to the success of low volume application and can achieve efficient dose transfer to the biological target.

Figure 3 illustrates this by showing the droplet size spectra from four different nozzles, juxtaposed to bands indicating the probable optimum size ranges from a biological point of view. Note also that there is a cubic relationship between a droplet's diameter (its 'perceived' size) and its volume (proportional to dose). Large droplets that bounce off leaves may still be appropriate for pre-emergence herbicides, but are wasteful in most other circumstances. The same volume of pesticide broken up into smaller droplets could make up a large number of effective doses where plants or insects are the target. The 110-03 flat fan nozzle, often fitted to tractor boom sprayers, is very widely used in western agriculture. At 300 kPa pressure it produces a 'medium spray' which includes droplet sizes ranging from those that are too small even to be appropriate for fungicides, to 'drops' that are >500 µm. In an attempt to reduce the <100 µm proportion, the same manufacturer produces a 'low drift' nozzle with an equivalent output; the proportion <100 µm has been halved to <4%, but this nozzle also produces a wide spectrum of droplet sizes, and the median diameter has been shifted from approximately 150 µm to >300 µm. Compare these spectra with two rotary nozzles: the Ulva+ set for application of water-based insecticide formulations and the 'Herbi' designed for spraying herbicides. Using the optimum droplet size criteria, appropriately set rotary atomizers can increase the volume of output in these ranges from <40% to approximately 80%.

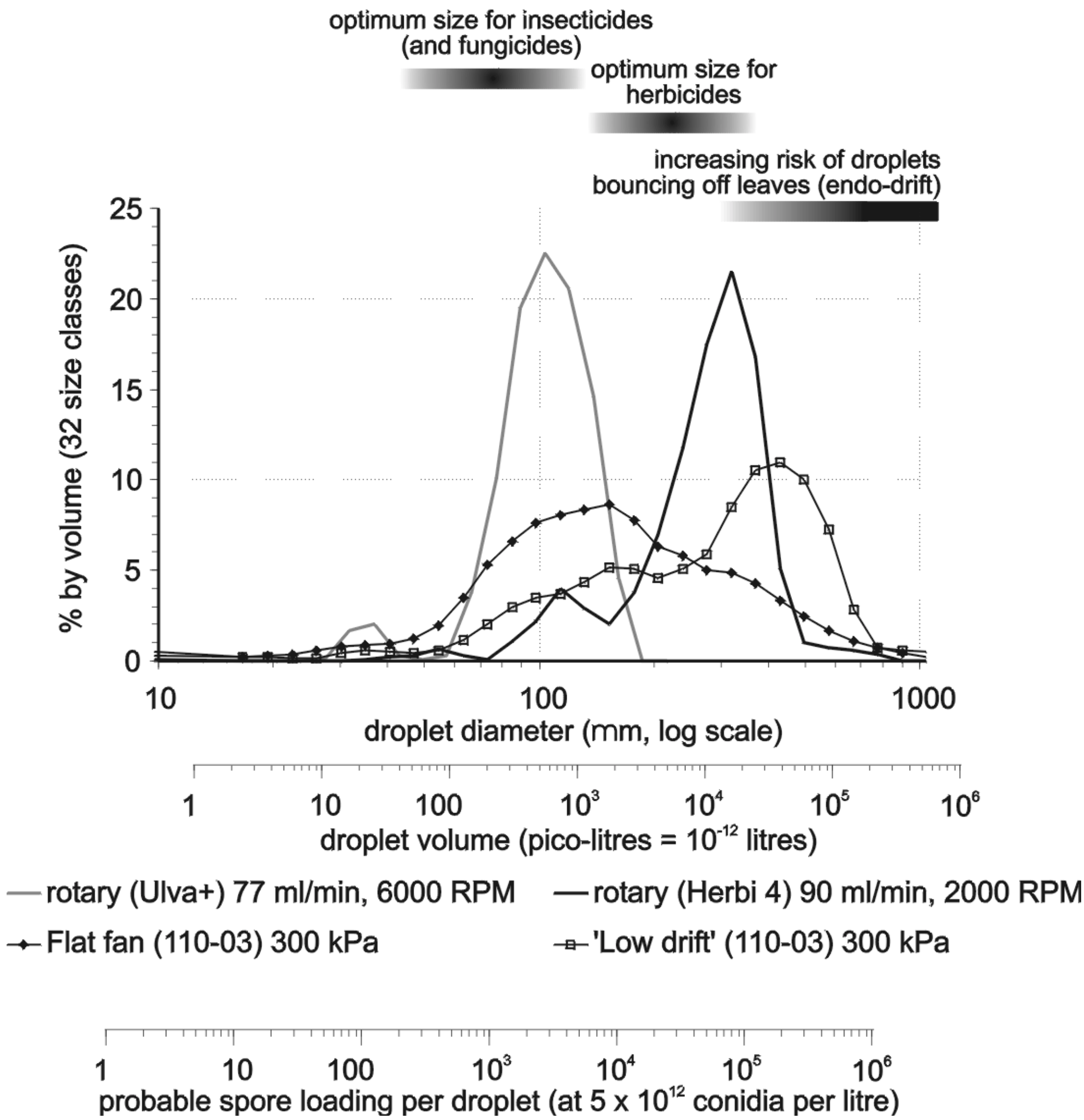

Figure 3. Droplet size spectra of output from four atomizers spraying water + 0.1% surfactant (Agral 90) measured by a 'Malvern 2600' particle size analyser.

Rotary atomization is not appropriate for all pest control si
are by far th
spraying pesticides. However much could be done to reduce wastage (and operator hazard) with conventional equipment, by better choice and maintenance of equipment. It is interesting to speculate how much of the money spent on pesticides shown in Figure1 could be saved by widespread adoption of improved techniques. If efficiency were to be doubled (eminently feasible from a technical point of view) then RPU could save mankind some US$15 billion annually. Perhaps there is indeed little incentive for pesticide manufacturers to promote improved application techniques.

Getting the Bugs Out

There has been much recent interest in biological pesticides, and the development of delivery systems for microbial agents provides an excellent example of RPU. Biopesticides are among the most specific agents available to the farmer; however, their share in the total pesticide market remains below 1%, and there have often been technical, logistic and commercial difficulties in providing the biological products that have been identified as most appropriate for IPM in some crops. Although widely liked by both ICM and IPPM protagonists, biopesticides will remain primarily subjects for discussion, unless the technical, commercial and conceptual issues can be resolved, so that more products appear on shelves and farmers want to use them.

Amongst perceived constraints are narrow target spectra, poor performance relative to cost, and inconsistent product quality, but a major problem with current use is the poor standard of application to crops, allied with a belief that horizontal transmission mitigates the need for good delivery systems. However, there are studies showing that, as with chemical pesticides, droplet size and coverage affects the efficacy of agents such as *Bacillus thuringiensis*. Unlike many chemical formulations, biopesticides are necessarily suspensions (as opposed to solutions) and the concept of dose transfer to the target pest in the form of particles must underlie the development of effective delivery. By monitoring efficacy over weeks (rather than days), some biopesticides are substantially more efficacious than their chemical rivals.

This can be illustrated by results gained with the international LUBILOSA Programme.LUtte BIologique contre les LOcustes et les Sauteriaux is a collaborative, multi-disciplinary research and development programme funded by the Governments of Canada (CIDA), the Netherlands (DGIS), Switzerland (SDC) and the UK (DfID). It was set up to develop envi-

spray campaigns in the 1980s caused public concern about the accompanying environmental impact of chemicals, and biological pest management methods are especially important in natural and semi-natural habitats. The programme has developed a mycoinsecticide based on an isolate of the fungus *Metarhizium anisopliae* var. *acridum*, which has been field tested against a number of acridid pest species, and is now recognised as an appropriate product for locust control in environmentally sensitive areas. In a recent series of operational trials against *Oedaleus senegalensis*, it was shown that although the organophosphorus chemical fenitrothion achieves an impressive 'knock down', hopper populations recover and two weeks after application a more profound population reduction was achieved in the plots sprayed at ULV rates with *Metarhizium* conidia. Residues of the fungus were more persistent than fenitrothion but had minimal impact on nontarget organisms – which may have enhanced field efficacy. However, it is not sufficient simply to demonstrate efficacy and register products in this way; there is a continuing need to promote and ensure the continued supplies of good quality, cost effective formulations. It appears that this is presently best achieved by partnership between publicly funded research groups (such as LUBILOSA) and small- to medium-sized commercial companies.

The Challenge

With the increasing supply of cheaper, considerably less toxic and more specific compounds, an open mind is important in providing reliable technical solutions to farmers' problems. Commercial pressures have encouraged the excessive promotion of single technology ('magic bullet') concepts, which have not delivered all that was promised. It is the use of techniques in combination with one another that offers the greatest potential for farmers to reduce costs and impact on nontarget organisms. When it is accepted that pesticidal intervention is indeed occasionally necessary, then RPU could provide a framework for interaction between IPM practitioners and providers of technical solutions. However, we must recognise that:

- In the interests of economic support, quality control and reliability of supply, RPU technologies (such as biopesticides, improved pest monitoring tools and application techniques) are most likely to succeed when provided by commercial concerns, rather than rural communities.
- Alliances are needed between research evelopment organizations and the -to medium-scale industries that have the best track record for sustaining RPU technologies.
- It is essential that farmers and other users understand the biological and technical concepts underlying these technologies. The relationship between technology providers (both institutional and commercial) and the needs of farmers is also vital for the successful implementation of RPU and other IPM technologies.
- A re-examination of appropriate environmental and regulatory policies at national and international level would also be most helpful.

RPU is not a new paradigm, but a sub-set of IPM. It recognises that pesticides have been around for more than a generation, and are likely to be around for at least another. Seeing pesticides as dangerous (and conversely biological control as safe) is over-simplistic and sometimes factually wrong. RPU is a mixture of old and new ideas to manage real problems such as pesticide resistance and environmental impact and, of most interest to the farmer, to provide robust but economic pest management.

[1]Brent, K.J.; Atkin, R.K. (*eds*) (1987) Rational pesticide use. Cambridge, UK; Cambridge University Press, 348 pp.

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Improving Hot Pepper Production in Jamaica

The Food and Agriculture Organization of the United Nations (FAO) is providing assistance to Jamaica, through a technical cooperation project, to improve production of its famous hot peppers (*Capsicum* spp.). At present, production and export of hot peppers is one of Jamaica's most important agricultural activities and has been identified as having great potential for development by the Government. The indigenous Jamaican Scotch Bonnet, renowned for its unique characteristics, is one of the best known and most prized of the Caribbean varieties in the export market. Over J$38 million (US$1.0 million) per annum are currently earned from the industry and more than 3000 people are directly or indirectly employed in it.

Maximizing production and hence returns from the crop are constrained by a number of factors, the chief of which are a shortage of good quality seed and the impact of various pests. The most important arthropod pests are gall midges (*Contarinia lycopersici* and *Prodiplosis longifila*), the broad mite (*Polyphagotarsonemus latus*) and aphids (*Aphis gossypii* and *Myzus persicae*). However, the gall midges constitute the most pressing problem, because they are considered pests of quarantine significance in the USA, which is a major market for the crop. Effective control measures need to be implemented urgently. At present, farmers rely heavily on chemical pest control methods – indeed, it is likely that the gall midge problem could be pesticide induced.

The FAO project, which was initiated in April 2000, aims to assist the Government of Jamaica with its hot pepper seed development programme, and amongst its objectives is the implementation of an IPM strategy for effective control of gall midges and broad mite. A number of preliminary activities have been initiated within the IPM programme so far. These include: identification of demonstration farmers' plots, installation of equipment, identification of laboratory facilities at Bodles Research Station, development of protocols for pesticide trials, looking at the role of indigenous natural enemies and preliminary laboratory studies on pest biology and their natural enemies. The Caribbean Agricultural Research and Development Institute (CARDI) has also been undertaking studies on both the hot pepper pests in question.

Farmer participatory research and training is also a key element of the FAO project. Towards this end, a national training workshop on farmer participatory approaches was undertaken in August 2000 where 15 extension workers were trained to develop and implement a farmer participatory IPM programme in six parishes in Jamaica. One concrete outcome of the workshop was progress in the development of a proposed curriculum framework for farmer training in hot pepper production techniques in which participatory IPM will be a major component.

Source: Pollard, G. (2000) FAO Assistance to Jamaica for improving hot pepper production, in part through development of an IPM programme for gall midges and broad mite. Caribbean*IPM* Knowledge Network, *Current Awareness Bulletin*, No. 2 (September 2000).

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Internet Round-up

In this issue, we give some Internet sites dealing with mammal biocontrol, to go with our news article on the subject. Australia and New Zealand are leaders in this field, and we concentrate on some of their resources. As a biological island with its own unique flora and fauna, Australia has suffered massively from the hosts of mammals imported since European settlers first colonized the continent 200 years ago. The Australian Pest Animal Control CRC site at:

http://www.pestanimal.crc.org.au

outlines pest problems caused by foxes, rabbits and mice, and their work to develop control methods for them. They are focusing on immunocontraceptive vacines and their delivery through baits or, by engaging biotechnology, through the agency of a virus genetically modified to carry the vaccine. However, native animals also cause problems in Australia, and the Australian Marsupial CRC works on the conservation of marsupials in their native environments combined with management solutions in problem situations. Research on fertility, development, genetics, immunology and virology being used to develop practical fertility-based management solutions is described at:

www.newcastle.edu.au/marsupialcrc

Also on this site is the proceedings of a conference on Managing Marsupial Abundance for Conservation Benefits held in Perth in 1998:

http://www.newcastle.edu.au/marsupialcrc/marsupsymp/index.html#contents

New Zealand interests in mammal biocontrol are described on the Landcare Research site <http://www.landcare.cri.nz>. The Biosecurity and Pest Management page at:

http://www.landcare.cri.nz/science/biosecurity/

describes brushtail possums as the country's worst vertebrate pests. Its Possum Information Pages <http://www.landcare.cri.nz/science/possums/> have information on their biological control including immunocontraceptive and fertility control techniques. Reflecting the concern about possums is the presence of a searchable bibliography at:

http://possum.massey.ac.nz

and lists of current research projects on possums (mostly in New Zealand) and a bibliography that includes many unpublished reports are also available in the Annual Reports of the National Science Strategy Committee for the Control of Possum and Bovine Tb at:

http://www.frst.govt.nz/public/possum/index.htm

In general, rabbit biocontrol in Australia and New Zealand probably springs most readily to mind when mammal biocontrol is mentioned. Information on rabbit haemorrhagic/calicivirus disease (RHD/RCD) introduction to Australia is archived at:

http://www.csiro.au/communication/rabbits/rabbits.htm

As well as providing extensive background to the rabbit problem and disease solutions, and a detailed guide to using and managing RHD in the field, it also describes responses to the accidental escape of the virus from quarantine Also interesting is the New Zealand Rabbit Biocontrol Advisory Group (RBAG) site at:

http://www.maf.govt.nz/MAFnet/articles-man/rbag/httoc.htm

The site comprises an information kit designed to bring together an overview of rabbit impacts, trends in pest management and information on RHD. RBAG was disbanded when permission to import calicivirus was received, but the site is a good source of information, some of it now of historical interest (for example, among frequently asked question, "Is RHD likely to arrive naturally in New Zealand? …an illegal introduction cannot be discounted…"). It provides an overview of viruses, mutation, and host specificity and switching in the context of the rabbit calicivirus.

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Announcements

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

Pilot in the Caribbean

CAB International in collaboration with the Caribbean Agricultural Research and Development Institute's (CARDI) Caribbean Agricultural Information Service and PROCICARIBE'S Caribbean IPM Network have set up a pilot Knowledge Network for IPM experts in the region. The primary target group is invited scientists and agriculturists in the Caribbean region, but key resource people from other geographic regions are also invited to participate to widen the knowledge base. The information on the network will be largely based on communications posted by the group's members. The network will solicit and disseminate the following four types of information:

- Short 'keynote' papers on specific subjects, posted with the objective of stimulating discussion among group members.
- Summary papers of member contributions for each topic area.
- A 'current awareness service' including contents and abstracts from international and national bibliographic databases, supported by provision of full text of key documents (copyright permitting) in either hardcopy or electronic format.
- Announcements of relevant regional/ international meetings, workshops, and courses.

The Internet provides new opportunities for agricultural research organizations to share and disseminate information. While not everyone in the Caribbean region yet has Internet access, even rurally-based scientists are beginning to be connected to email. The demand is growing, and most governments, recognising its potential, are investing in new information technology even in a period of economic austerity. Soon, many more scientists and farmers will be able to access and use email to participate in this kind of knowledge network. The pilot will therefore be evaluated, and from this recommendations on the structure and composition of future Knowledge Networks in the region will be formulated. It is anticipated that the IPM Knowledge Network will continue in some form, as discussed and agreed among the members.

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Knapweed Symposium

An international knapweed symposium will be held in Coeur d'Alene, Idaho, USA on 15-16 March 2001, in conjunction with the annual Western Society of Weed Science meeting. The purpose of the Symposium is to present new information on the biology, ecology, and management of *Centaurea* (sensu latu) species (including spotted knapweed, diffuse knapweed, squarrose knapweed, Russian knapweed and yellow starthistle). The symposium is sponsored by the Western Society of Weed Science, in cooperation with the US Forest Service, Bureau of Land Management, USDA Agriculture Research Service, University of Idaho, Western Weed Coordinating Committee, the Idaho Department of Agriculture, and DowAgrosciences. For further information see the website at: http://www.sidney.ars.usda.gov/knapweed/

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Cuba Hosts Plant Health Seminar

The IVth International Scientific Seminar of Plant Health will take place in Varadero, Cuba on 11-15 June 2001. The following scientific meetings will take place:

- IV International Scientific Seminar of Plant Health
- X Latin American Workshop of Whiteflies-Geminiviruses
- 33rd Annual Meeting of the Organization of Nematologists of Tropical America (ONTA 2001)
- 41st Annual Meeting of the American Phytopathological Society, Caribbean Division (APS-CD 2001)
- VII Symposium of Ant Pests
- II Latin American Congress of the Neotropical Regional Section of the International Organization for Biological Control
- Workshop for scientific information on plant protection
- International workshop on pests and diseases in banana: current situation and challenges for the new century (INISAV-CENSA-PRO*MUSA*)

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Practising Biological Control

A conference entitled 'The Practice of Biological Control: Importation and Management of Natural Enemies and Agents will be held on 2-5 August 2001 at Montana State University in Bozeman, USA. Conference details are given on the website at:
http://opal.msu.montana.edu/conf_services/biocontrol/index.htm
Registration is limited to the first 250 to register.

The symposium is intended for practitioners in all disciplines of biological control, including entomology, insect pathology, nematology, plant pathology, and weed science, and is co-sponsored by the International Organization for Biological Control, Nearctic Regional Section (IOBC-NRS), the Experiment Station Committee on Organization and Policy (ESCOP-BCWG) and the National Biological Control Institute (UDSD-APHIS-PPQ-CPHST-NBCI).

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Fertility Control

The 5th International Symposium on Fertility Control in Wildlife will be held on 19-22 August 2001 at the Kruger National Park, South Africa. Topics covered will include current field applications, on-going field trials (including those in zoos or sanctuaries), research in progress (which will form the heart of the symposium), ethical, social, cultural and political aspects of population control, and regulatory issues.

Contact: 5th International Symposium on Fertility Control in Wildlife,
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Combating Invasive Plants

The 6th International Conference on the Ecology and Management of Alien Plant Invasions (EMAPi) will be held on 12-15 September 2001 at Loughborough University, Leicestershire, UK. The organizers are circulating a short questionnaire for intending participants to ensure that the conference will reflect the current interests of alien plant invasion research.

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Africa Online

African Journals Online (AJOL 2000) is a website offering on-line access to the tables of contents and abstracts of articles from some 50 journals in agricultural sciences, science and technology, health and social sciences, published in Africa.
Internet: http://www.inasp.org.uk/ajol/

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