Eradication of introduced *Bactrocera* species (Diptera: Tephritidae) in Nauru using male annihilation and protein bait application techniques

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Abstract Four introduced *Bactrocera* species were recorded in the Republic of Nauru in 1992. A programme to eradicate the four species was implemented between October 1998 and December 2000. The objectives were to eradicate the introduced pest fruit flies that were a threat to neighbouring Pacific Island countries and territories, to test the efficacy of Fipronil as an alternative toxicant to malathion for the management of fruit flies, to train national plant protection and quarantine staff in fruit fly eradication and emergency response techniques, to establish and up-grade the quarantine services in Nauru, and to increase fruit availability for local consumption. A combination of male annihilation and protein bait application techniques was used for eradication. The Male Annihilation Technique involved distributing fibreboard ('Canite') blocks impregnated with male fruit fly lure (methyl eugenol and/or cue-lure) and the insecticide Fipronil in a loose grid, resulting in at least 300 blocks per km² over Nauru. The blocking campaigns were repeated every eight weeks from late October 1998. The protein bait application technique involved spraying host fruit trees in hot spot areas with protein insect lure and Fipronil gel on a weekly schedule. Three of the four species, namely oriental fruit fly (*Bactrocera dorsalis*), Pacific fruit fly (*B. xanthodes*), and melon fly (*B. cucurbitae*), were declared eradicated. Populations of mango flies (*B. frauenfeldi*) still persist. The Government drafted and promulgated a new Agricultural Quarantine Act and established an Agricultural Quarantine Service in Nauru. A major benefit of the eradication programme is that people in Nauru once again are able to eat mangoes and breadfruit after a decade of near-total losses due to introduced fruit flies.

Keywords Tephritidae; fruit flies; eradication; male annihilation technique.

INTRODUCTION

Fruit flies (family Tephritidae) pose a significant threat to fruit and vegetable production and to the unimpeded export of fresh fruits and fleshy vegetables throughout the world. In the Pacific region, over the past 25 years, exotic fruit flies invaded several countries causing direct losses to production of fresh fruits, imposition of trade restrictions by importing countries, and implementation of expensive eradication or suppression programmes to rid countries or parts of countries of the introduced pests. For example, Asian papaya fruit fly (*Bactrocera papayae* (Drew and Hancock)) gained entry to Papua New Guinea (PNG) in about 1992 and was recorded in northern Australia near Cairns in 1995 (Drew 1997). The outbreak in the Cairns area was subsequently eradicated at a cost of about AU$35 million. Other members of the *dorsalis* complex of fruit flies gained entry into several areas of the Pacific region. Oriental fruit fly (*B. dorsalis* (Hendel)) expanded its geographical range into Tahiti and Moorea in French Polynesia in about 1996. In 1997, *B. philippinensis* Drew and Hancock was recorded in, and subsequently eradicated from, the Darwin area of the Northern Territory of Australia. *B. occipitalis* (Bezzi) and *B. philippinensis* were recorded in the Republic of Palau in Micronesia in 1996. Allwood *et al*. (1999) and McGregor (2000) examined the technical and economic feasibility of eradicating these species and, subject to funding support, an eradication programme may commence in October 2001. Melon fly (*B. cucurbitae* (Coquillett)) was introduced into the Western Province of Solomon Islands around 1984 and now has spread as far south as Guadalcanal in the Central Province of Solomon Islands (Hollingsworth *et al*. 1997). Mediterranean fruit fly (*Ceratitis capitata* (Wiedemann)) was recorded in New Zealand in 1996 and was successfully eradicated at a cost of approximately NZ$6 million.

Staff of the South Pacific Commission (now called the Secretariat of the Pacific Community (SPC)) conducted a survey of fruit flies in the Republic of Nauru in November 1992, using five pairs of modified Steiner traps located in urban, village, secondary forest, and beach areas and on a vegetable farm. One trap of each pair was baited with methyl eugenol plus 50% malathion emulsifiable concentrate in a ratio of 3:1 by volume and the other baited with cue-lure and malathion. This survey recorded that four species of fruit flies were established. The introduced species were oriental fruit fly, Pacific fruit fly (*B. xanthodes* (Broun)), melon fly, and mango fly (*B. frauenfeldi* (Schiner)), the first two species being attracted to the male lure methyl eugenol and the last two being attracted to cue-lure (H. Kumar pers. comm.). Chu (1993) of the National University Taiwan trapped large numbers of oriental fruit flies and melon flies in the east, southeast and Buada Lagoon areas of Nauru.

Mango fly is widespread in Micronesia (except in Guam and Commonwealth of the Northern Mariana Islands (CNMI)), PNG, Solomon Islands, and northern Queens-

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land. Pacific fruit fly is widespread from Fiji Islands east to Cook Islands. In contrast, the regional distribution of melon fly is restricted to PNG, Guam, CNMI, Solomon Islands and Nauru and the oriental fruit fly to French Polynesia and Nauru. Both mango fly and oriental fruit fly have very wide host ranges and, as adequate fruits were available at most times of the year, high populations were present at all times in Nauru. Pacific fruit fly was restricted primarily to *Artocarpus* spp. and, consequently, high populations of the fly occurred in October to April. Melon fly is restricted mainly to hosts belonging to the family Cucurbitaceae. Melon fly populations were generally low, but present throughout the year.

Regional organisations, such as the SPC, Food and Agriculture Organisation of the United Nations (FAO), and the United Nations Development Programme (UNDP), and the Governments of the Pacific Island countries and territories (PICTs) strongly recommended that oriental fruit fly and melon fly be eradicated from Nauru, for several reasons. Eradication would reduce the threat that these damaging fruit fly species posed to fruit production and export in neighbouring PICTs, protect advances made in regional management of fruit flies since 1990, and provide an ideal opportunity to facilitate hands-on training in fruit fly eradication techniques and emergency response planning to many plant protection and quarantine staff in the Pacific region. Also, eradication of oriental fruit fly, in particular, would increase the availability of fresh fruits in Nauru, a very scarce resource since at least 95% of fruits, such as mangoes and guavas, were infested with fruit fly maggots and inedible. To protect the investment of the eradication effort, the Government of the Republic of Nauru was strongly encouraged to draft and promulgate its first Agricultural Quarantine Act and develop a small, appropriately trained Agricultural Quarantine Service to ensure fruits entering Nauru were free from damaging fruit flies and other exotic pests.

The public of Nauru reacted adversely to the prospect of using malathion as the toxicant for eradication, primarily because of its unacceptable odour. For this reason, Fipronil [(±)-5-amino-1-(2,6-dichloro-K, K, K-trifluoro-p-tolyl)-4-trifluoromethylsulfinyl-pyrazole-3-carbonitrile], a product of Aventis CropScience Pty Ltd, was selected as an alternative toxicant and was laboratory and field-tested for use in the eradication programme.

Nauru proved to be an ideal place to conduct an eradication programme for fruit flies. It is an isolated island, so the risk of re-introduction of exotic fruit flies was low. It is 41 km south of the Equator at 166º 56´ East longitude. Nauru is about 650 km south-west of Kosrae in Federated States of Micronesia and a similar distance almost due west from Tarawa in Kiribati, both of which are infested with mango fly. It is about 1000 km northeast from Honiara in Solomon Islands, the closest infestation of melon fly. The closest infestation of oriental fruit fly is in Hawaii, about 3600 km northeast of Nauru.

Nauru is 5.5 km from north to south and 4.5 km east to west and covers an area of 21.2 km², with a coastline of 19.3 km. It is an uplifted limestone island with a narrow coastal belt encircling a limestone escarpment reaching 30-70 m above sea level. Much of the escarpment and the interior of the island (referred to locally as Topside) are inaccessible due to severe land disturbances caused by extensive phosphate mining. The Buada Lagoon area in the central southwest of the island is fertile, surrounds a small brackish lake, and supports small groves of mango (*Mangifera indica*), guava (*Psidium guajava*), and breadfruit (*Artocarpus altilis*) trees. Soursop (*Annona muricata*) forms an understorey in most of the Buada Lagoon area. The Buada Lagoon area is a residential area with fruit trees growing in backyards. Nauru is located in the dry belt of the equatorial oceanic zone, with a mean daily temperature range of 26-32°C and an average annual rainfall of 1500 mm (range of 300-4572 mm). Long droughts are common, often causing the death of native trees, wild cucurbits, and breadfruit trees. The flora is poor relative to other Pacific islands, partly due to the mining activity. The range of host fruits for fruit flies is limited to plants such as Pacific almond (*Terminalia catappa*), *Guettarda speciosa*, wild guavas (*Psidium* spp.), mango, soursop, breadfruit, *Citrus* spp., and mountain apple (*Syzygium malaccense*).

This paper summarises the methods used in eradicating three species of fruit flies in Nauru, the results obtained, and the technical and management lessons learnt during the eradication operations.

METHODS

The techniques available for the eradication of fruit flies worldwide usually follow an integrated approach, including fruit movement controls, destruction of fallen and unwanted fruits, biological control using inundative releases of parasitoids, protein bait application, application of systemic larvicides to fruit trees to kill eggs and larvae of fruit flies, ground application of an insecticide to kill larvae and emerging adults, male annihilation, and release of sterile flies. In the case of the eradication programme in Nauru, the major techniques selected were managing fallen fruits, developing adequate quarantine regulations to prevent re-introduction of exotic fruit flies, male annihilation technique (MAT), and protein bait application technique (BAT). Other techniques were unacceptable environmentally (e.g., ground application of insecticide or cover spraying trees with systemic insecticides) or were economically or technically inappropriate for a small island such as Nauru (e.g., sterile insect technique).

Organisation

The Nauru Fruit Fly Eradication (FFERAD) Programme belonged completely to the Government of the Republic of Nauru, with technical and financial support being provided through the FAO/UNDP/AusAID/SPC Project on Regional Management of Fruit Flies in the Pacific

(RMFFP). Financial support was also received from the Crawford Fund for International Agricultural Research. Aventis CropScience provided Fipronil products at no cost to the programme. The Nauru Government arranged teams for blocking from the Departments of Youth, Health, and Works, and from the Nauru Phosphate Corporation and the Buada Lagoon community. The Department of Island Development and Industry provided the coordination role and staff for the treatment of blocks, supervising MAT and BAT operations, servicing of traps, fruit sampling and processing, public awareness, and reporting on progress. Staff from the RMFFP assisted with the monitoring of the operations and progress of the eradication programme, with a special focus on quality assurance for the treatment of blocks and the distribution of blocks and protein bait.

Effective public awareness and cooperation were recognised as being essential to the success of the programme and were carried out by producing a FFERAD Newsletter during each blocking campaign and distributing these to all government departments, the Nauru Phosphate Corporation, the general public, and to school children. Public meetings and regular briefings of government personnel and the public were undertaken.

Management of fallen or unwanted fruits

Destruction of fallen, over-ripe, or unwanted fruits was not practised in the true sense, although destruction of fruits was strongly encouraged through publicity programmes. However, community leaders actively encouraged children and adults not to climb mango trees and other fruit trees to shake branches to collect fruits. When the practice of shaking branches to collect fruits was stopped, there were fewer fruits left on the ground as egg-laying sites for oriental fruit flies and mango flies. The public was encouraged by community leaders to take only fruit that had fallen to the ground or that was obviously ripe on the trees and to harvest sufficient fruits for their use rather than discarding unused fruits. The public was encouraged not to plant cucurbits until after the melon fly was declared eradicated.

Despite this effort, wild fruits such as Pacific almond and *G. speciosa*, were not collected and destroyed and, as a result, significant breeding sites for mango fly, in particular, were available. This occurred especially on Topside, where individual plants or small clusters of both host species were present and virtually inaccessible to people carrying out treatments.

Male annihilation technique (MAT)

The MAT aims to reduce the male fruit fly population to such a low level that no mating occurs. This may be achieved by distributing, at regular intervals over a wide area, a carrier containing a male lure plus a toxicant. The effectiveness of the MAT may be severely reduced if the carrier loses its attractiveness or toxicity before the end of the interval selected. Carriers may be made of fibreboard blocks (Steiner and Lee 1955), coconut husk blocks (C. Garnier pers. comm.), paper mâché discs or rectangles (R. Bull unpublished), pieces of cotton string or rope (Bateman 1982), or thickened gels (Cunningham *et al*. 1975). In Nauru, fibreboard blocks (50 mm x 50 mm x 12.7 mm) were chosen as the carrier. The blocks were cut from sheets of Standard Canite (supplied by Pacific Islands International, Kirwan, Queensland). Each sheet (2440 mm x 1220 mm x 12.7 mm) produced about 1000 blocks. Approximately 10% of the sheet was lost during the cutting process done by using a circular saw at the Nauru Phosphate Corperation workshops.

The formulation of Fipronil used was a special proprietary premix, provided by Aventis CropScience Pty Ltd in Brisbane. It contained 278 g active constituent/*l* initially, but this was thought to be slightly unstable and may have resulted in crystals settling out. The final premix contained 250 g active constituent/*l*. Initially, it was used at the rate of 3.1 ml/*l* of male lure, but this rate was changed to 4.0 ml/*l*. This premix is virtually insoluble in water, so would be very stable in the block. Fipronil is virtually odourless and so this feature overcame one of the major concerns of the public in Nauru. Laboratory bioassays conducted in Fiji Islands on Pacific fruit fly and in Brisbane on Queensland fruit fly (*B. tryoni* (Froggatt)) showed that Fipronil was effective in killing these fruit fly species at low dosages (R. Bull unpublished). Also, observational evidence indicated that, because Fipronil takes several hours to kill flies, an added advantage of transmission of Fipronil from males to females during mating might exist.

The treatment of fibreboard blocks with the male lure and Fipronil was done in used 200 *l* steel drums cut longitudinally to form 100 *l* troughs. The blocks were loosely packed into rectangular baskets covered in galvanised chicken mesh, which fitted into the 100 *l* troughs. Approximately 800 blocks were treated at one time. A mixture of male attractant and Fipronil was poured over the blocks in the trough, with the excess that drained into the trough being ladled over the blocks until the blocks had absorbed a prescribed amount of the mixture (see *Stages 1* and *2* on page 23). Random samples of 100 blocks were taken at intervals during the treatment and weighed to determine when sufficient lure plus Fipronil had been absorbed per block. Blocks were also examined for absorption by breaking them in half. The blocks were allowed to drain in the 100 *l* troughs before being stored in plastic garbage bins. Blocks were nailed with 50 mm steel nails. Galvanised nails were not used because reports from the eradication programme for Asian papaya fruit fly in northern Queensland indicated that phytotoxicity to some palm trees occurred (R. Drew pers. comm.).

Nauru was subdivided into seven sectors, five around the coastline covering residential areas, the Buada Lagoon area, and the mined area or Topside. The areas of these sectors were 0.7-1.7 km², with the exception of Topside, which was 14 km². Each sector was allocated to a team to distribute the blocks treated with male lures and Fipronil. Initially, there were sufficient teams for each team to be responsible for a particular sector, but, as the number of teams decreased to four or five, teams had to cover more than one sector. The aim of the MAT was to cover all sectors and distribute the blocks in about 1.5-2 days every eight weeks. Each team was responsible for mapping, on a daily basis, the area covered by blocking, the number of blocks distributed, and any complaints from the public.

The aim of the programme was to distribute the blocks at a minimum density of 300-400 blocks per km² over the whole of Nauru. In areas that were readily accessible by ground teams, the objective was to nail one block to a tree in the shade of foliage at a height of at least 2 m on a grid of about 50 m. If this were achieved, the density of blocks would be about 400 blocks per km². However, in urban or village areas and in areas of high incidence of fruit flies (e.g., in the Buada Lagoon area), blocks were distributed at densities much higher than required (i.e., up to 1500-1700 blocks per km²). Generally, however, the density of blocks in urban and accessible native vegetation areas was acceptable at 400-700 per km². In the accessible mined area of Topside, blocks were distributed at 50 m intervals along all roads, train tracks, and motorcycle and walking tracks that radiated from a central point and along roads that ran around the coastal edge of the escarpment. In mined, inaccessible areas on Topside, blocks were thrown or fired from slingshots into native vegetation patches. The density of blocks on Topside was, because of the terrain, 60-135 per km².

Protein bait application technique (BAT)

The principle of BAT uses the nutritional need of female fruit flies for protein before they are capable of laying viable eggs. Sexually immature female flies actively seek protein sources such as bacteria and other exudates on the leaf and fruit surfaces of the host trees. Male and sexually mature female flies also feed on protein. Adding a toxicant to the protein and applying the mixture in large droplets or spots to the underside of leaves in host trees is a very effective method of controlling fruit flies by killing female flies before they reach the egg-laying stage. Used on its own, or preferably as an adjunct to MAT, BAT is an effective eradication technique. Aventis CropScience Pty Ltd in Brisbane developed the protein bait gel used in Nauru. It comprised a mixture of protein autolysate, called Mauri Pinnacle Protein Insect Lure – Low Salt (420 g of protein/*l*) (MPPIL) (supplied by Mauri Yeast Australia, Toowoomba, Australia), Fipronil gel powder, and water. The Fipronil gel was prepared by sprinkling the Fipronil gel powder on the surface of water at the rate of 5 g of powder per litre of water and stirring vigorously until a thickened gel was formed. Protein autolysate was mixed with the gel at the rate of 30-50 ml of MPPIL per litre of gel immediately before use.

This mixture was applied to the undersides of foliage of host trees in spots of 10-15 ml at a rate of 25 spots per hectare. For each treatment, 180-200 *l* of protein/Fipronil gel bait were applied per week, providing coverage of 480-800 ha. Application was supposed to be done weekly, especially in areas where persistent fruit fly populations (commonly referred to as 'hot spots') occurred. However, due to problems of staff availability and commitment and non-arrival of supplies owing to inadequate planning and lack of regular air and sea freight services, treatments were not as consistent as they should have been. Although applications were done in November 1998 and June 1999, the main body of applications did not start until July 1999 and, even then, there were interruptions to the spray schedules in September and December 1999 and at various times during 2000.

Several types of pressurised sprayers were tested during the programme, but the most suitable and durable was the single-action 'Rega' sprayer made of brass, with a 5 *l* chemically resistant plastic container, with a sling for carrying on the shoulder.

Fruit fly monitoring procedures

Trapping

The number of modified Steiner traps (Drew 1982) for monitoring fruit fly populations varied as the programme progressed and as the numbers of flies decreased. The numbers of traps increased from 10 in October 1998, to 12 in February-May 1999, to 25 in May-September 1999, and to 41 in October 1999. This final trapping density represented two traps per km². Each site consisted of a pair of traps. One trap in a pair was baited with methyl eugenol plus malathion (50% emulsifiable concentrate) mixed in a ratio of 3:1 and the other with cue-lure and malathion in the same ratio. The traps were cleared weekly and the flies were identified and counted. Lures and insecticide were replenished every eight weeks, coinciding with the commencement of each blocking operation. No liquid protein traps (Drew 1982) were used to assess the numbers of female flies; this feature was possibly a deficiency in the programme.

Fruit sampling

Sampling of the major fruits were undertaken periodically to assess the percentage of fruits infested by the respective species. The sampled fruits covered 15 plant families and 19 species, including mango, soursop, papaya (*Carica papaya*), guava, mountain apple, lime (*Citrus aurantifolia*), vi (*Spondias dulcis*), Pacific almond, *G. speciosa*, *Ochrosia elliptica*, bitter gourd (*Momordica charantia*), *Calophyllum inophyllum*, *Hernandia* sp., *Ficus* sp., and *Morinda citrifolia*. Large samples of fruits were randomly collected, mainly from the ground, weighed, counted, and set up in bulk or individually in separate plastic containers over sieved sawdust. They were held in an air-conditioned laboratory operating at 25-28°C. Flies were allowed to emerge and were fed on water and sugar for about five days, killed, identified, and counted. The percentage of fruits infested was also determined. As an example, 136 kg of mango fruits made up of 1750 fruits and 12.2 kg of *G. speciosa* fruits made up of 1289 fruits were sampled and put through the laboratory. Fruit sampling demonstrated very clearly the impact of the MAT and BAT on oriental fruit fly damage to mango fruits. Together with trapping results, fruit sampling identified the hot spots or areas where breeding populations of flies persisted.

Staging of the eradication campaigns

The eradication programme was planned in four stages. Initially, the plan was to focus on the eradication of oriental fruit fly and Pacific fruit fly; the flies attracted to methyl eugenol. The major reason was that methyl eugenol attracted flies, historically, were more responsive to the MAT technique than flies attracted to cue-lure. However, in a programme where four species are being targeted, maintaining a high degree of flexibility in operations was essential.

Stage 1: October 1998-January 1999

Stage 1 consisted of two blocking campaigns, one in late October/early November and another in December. These campaigns were less than eight weeks apart, but this was designed to avoid the pre-Christmas period. The fibreboard blocks were treated with methyl eugenol and Fipronil only at the rate of 10-12 ml of methyl eugenol plus Fipronil per block. One protein bait application was carried out in November as a preliminary field test of the newly developed protein/Fipronil bait.

Stage 2: February-October 1999

Stage 2 covered campaigns 3-7 and involved a major change to the composition of the lures in the fibreboard blocks. A mixture of cue-lure, methyl eugenol, and Fipronil was used to treat blocks. This was done to take advantage of the very low numbers of melon fly, which resulted from the low incidence of wild and cultivated cucurbit hosts due to the severe drought. As well as putting extra pressure on the population of melon fly, maintaining pressure on the seriously depleted populations of male flies of oriental fruit fly and Pacific fruit fly was also necessary. The new mixture consisted of 3 *l* of methyl eugenol plus 6 *l* of cue-lure/ethanol in a ratio of 1:9 by volume plus 28 or 36 ml of Fipronil, depending on the concentration of Fipronil in the special premix. The reasons for mixing cue-lure with ethanol was to reduce the cost using ethanol solely as a dispersant and also increase the ease of absorption of cue-lure into the fibreboard block. The amount of lure/Fipronil per block was increased to 12-15 ml per block, to ensure that there was sufficient methyl eugenol present to remain active for eight weeks under Nauru conditions.

Stage 3: November1999-October 2000

Stage 3 covered campaigns 8-13. As Pacific fruit fly persisted in very small numbers at a limited number of locations and the percentage of traps with positive records of mango fly remained at about 30%, the decision was taken to revert to dispersing blocks treated with methyl eugenol and Fipronil only and to commence distributing blocks treated with cue-lure and Fipronil only. Mixing of methyl eugenol and Fipronil followed the system used for Stage 1. Cue-lure was diluted with ethanol in a ratio of 1:9 as in Stage 2 and mixed with 4.0 ml of Fipronil per litre. 12-15 ml of cue-lure and Fipronil was absorbed per block. The methyl eugenol treated blocks were distributed at a density of 400-700 per km², while the cue-lure treated blocks were distributed at a density of 800-1000 per km².

Stage 4: December 2000 to present

Stage 4 involved the introduction of new technology called BactroMAT M-E and BactroMAT C-L bait stations during campaign 14 on 4-8 December 2000. This involved impregnating papier-mâché discs, approximately 38 mm in diameter and 1.5 mm thick, with lure and Fipronil at Aventis CropScience in Brisbane. Relatively small numbers of BactroMAT M-E bait stations (about 2500) were distributed to ensure that Pacific fruit fly was eradicated. About 10,000 BactroMAT C-L bait stations have been distributed since December 2000. In February 2001, the use of BactroMAT M-E bait stations was terminated.

RESULTS AND DISCUSSION

Eradication of methyl eugenol-responding fruit flies

Oriental fruit fly

Oriental fruit fly occurred in very large numbers throughout the coastal area and around Buada Lagoon. For example, during October 1998, an average of 72.4-126.1 oriental fruit flies were trapped per day. At one site in the Buada Lagoon area, over 2500 oriental fruit flies were caught in one trap in a 30-hour period. Although oriental fruit flies were present in Topside, examination of fruits of Pacific almond and mango showed that there were no breeding populations as there were on the coast or in the Buada Lagoon area. Also, the drought had reduced fruiting of Pacific almond and *C. inophyllum* to a minimum. Most flies trapped on Topside were probably flies migrating from the coast or Buada Lagoon area through the area.

After two MAT campaigns using methyl eugenol/Fipronil blocks and one BAT treatment using Bactrogel protein bait, oriental fruit fly was not recorded from traps after 15 January 1999. No flies were reared from fruits after 6 December 1998. Oriental fruit fly was declared eradicated in October 1999.

Pacific fruit fly

Pacific fruit fly occurred in reasonable numbers in several areas of Nauru, considering the host range was limited. For example, in October 1998, 3.6-4.7 flies were trapped per day. Most of these flies originated from the Buada Lagoon area and the Nibok Forest and the adjacent Nauru Phosphate Corporation residential areas in the northwest and west of Nauru. Very few Pacific fruit flies were recorded on Topside, where hosts were rare. Although the initial blocking campaigns reduced fly numbers in traps to zero over the period 3 November 1998 to 10 February 1999, small numbers of flies were caught intermittently until 16 February 2000. Flies were recovered from breadfruit samples until November-December 1999. The final eradication was brought about only when methyl eugenol was separated from cue-lure in blocks in December 1999. Pacific fruit fly was declared eradicated in October 2000.

There are two possible reasons for the persistence of Pacific fruit fly beyond the time at which oriental fruit fly was last recorded in January 1999. There was evidence that Pacific fruit fly does not feed as readily on methyl eugenol as other flies attracted to this lure (e.g., the *dorsalis* complex of fruit flies). In Fiji Islands, fruit fly workers observed live Pacific fruit flies in traps that were newly baited with methyl eugenol and malathion on many occasions (A. Allwood pers. obs.). Also, combining the two lures on one block may reduce the effectiveness of each lure. The amount of methyl eugenol impregnated into each block was reduced to about 4-5 ml when both lures were impregnated into the same blocks, compared to 10-12 ml, when the block was treated with methyl eugenol alone. Previous evidence showed that too little methyl eugenol added to carriers might result in the attractant not lasting for the full eight weeks (Lloyd *et al.* 1998; Cunningham 1989; Koyoma *et al*. 1984).

Eradication of cue-lure responding fruit flies

The effectiveness of cue-lure in MAT is recognised as being less than that of methyl eugenol (Bateman 1982). Some male flies apparently achieve sexual maturity and have the opportunity to mate before their response to cue-lure is fully expressed. Consequently, while using cue-lure for MAT may significantly reduce populations of cue-lure responding flies, small residual populations are left and result in continuation of the population, unless other forms of fruit fly management are implemented. Often the use of protein bait sprays or sterile insect technique needs to be incorporated into a programme to ensure complete eradication.

Melon fly

In late October 1998, melon fly was recorded from 30% of the traps baited with cue-lure, with 2.2 flies per trap per day. By taking advantage of virtually no wild cucurbits due to a prolonged severe drought of about two years and the lack of backyard or commercial cucurbit production, the impact of a single protein bait spray application using an early formulation of Aventis's Bactrogel in November 1998 and the use of cue-lure for MAT from February 1999 was remarkable. No melon flies were recorded from the very few cucurbit samples that were taken and none were recorded in traps from 1 February 1999. Melon fly was declared eradicated in October 1999. This is the first time worldwide that melon fly has been eradicated using these methods.

Mango fly

The programme on eradication of mango fly is still operating. Mango fly occurred in all traps in Nauru, often in very large numbers, especially in areas such as Buada Lagoon and Nibok Forest on the west coast. In October 1998, 379-912 flies per day were trapped. These fly numbers were typical of mango fly in other Micronesian countries, such as in Pohnpei in Federated States of Micronesia (Leblanc and Allwood 1997). Mango (0.12-2.46 flies per fruit), guava (2.0-27.1 flies per fruit), Pacific almond (3.8-15.1 flies per fruit), and *G. speciosa* (0.2-1.7 flies per fruit) contributed to the large populations of mango flies. As a result of the MAT programme using cue-lure and Fipronil, either in combination with methyl eugenol or alone, the numbers of flies were reduced to 0.02-0.03 per trap per day by April 2000. The percent of traps with positive records of mango fly decreased from 35.9% in early January 2000 to 7.7% on 5 April 2000. Reduced numbers of mango fly were due to changing to blocks treated with cue-lure/Fipronil alone and a concerted effort in protein bait spraying using Bactrogel, especially in the Buada Lagoon and Nibok Forest areas. Unfortunately, since then, mango fly numbers have increased substantially, due mainly to reduced local commitment, ineffective distribution of blocks or BactroMAT C-L, irregular bait application, and insufficient coverage by protein bait sprays and blocks.

Quarantine preparedness

The Government of the Republic of Nauru drafted and promulgated its first Agricultural Quarantine Act to allow for protection against re-entry of produce infested with exotic fruit flies or other quarantinable pests. Training of a small corps of four quarantine officers is being done in Pohnpei under the guidance of the SPC Plant Protection (Micronesia) Project. The quarantine surveillance system of trapping is being maintained as an early warning system for Nauru. Staff are trained in emergency response procedures for exotic fruit flies and supplies are available if a response is necessary.

Benefits and lessons learnt

Nauru people now have access to a limited amount of fresh fruits (e.g., mangoes, guavas, soursop, mountain apples, and breadfruit), which are virtually free of damage by fruit flies. Public interest in growing tropical and sub-tropical fruits has been generated, resulting in a project for a small nursery for propagation of planting material of exotic fruit trees being developed by the Departments of Youth and Education. This approach is a natural flow-on from the successful eradication programme and has potential to substantially increase the availability of wholesome, fresh food for a society that has unacceptably high incidences of obesity, coronary disease, and diabetes. To improve the diets of the people by substituting even small amounts of fresh fruits may have a major impact on the health of people in Nauru.

Improving quarantine capacity in Nauru overcame a void in the quarantine chain across the Pacific and provided greater plant protection, both nationally and regionally. The eradication programme in Nauru provided the opportunity for hands-on training on fruit flies, eradication techniques for fruit flies, quarantine surveillance, and emergency response planning to cope with exotic outbreaks. Since October 1998, over 40 plant protection and quarantine staff from 18 PICTs (American Samoa, Cook Islands, Federated States of Micronesia, Fiji Islands, Guam, Kiribati, Marshall Islands, New Caledonia, Niue, Palau, PNG, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu, and Wallis and Futuna), New Zealand, and the SPC Plant Protection Service spent 2-4 weeks in Nauru undergoing field training. Part of this training included the drafting of emergency response plans for the eradication of introductions of exotic fruit flies for the respective PICTs.

The major lessons learnt during this eradication exercise are that having early warning systems in place and having a well documented, and preferably tested, emergency response strategy will save an enormous amount of time and funds in the event of an incursion of an exotic pest. Also, the technologies for eradication of many fruit fly species are available, but the best technology is only as good as the technical and management commitment and support of the field operatives and the government. Premature reduction of inputs into MAT or BAT or quarantine in a fruit fly eradication programme and reduced commitment may be disastrous to the programme and also undermine the confidence in the technology. There are deficiencies in the technologies available for eradication of some fruit fly species, especially those that do not respond to either methyl eugenol or cue-lure. The deficiencies exist in not having adequate methods of eradication, but also in not having reliable quarantine surveillance systems that will allow authorities to detect incursions of pest species as early as possible.

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