THE ERADICATION OF *AEDES AEGYPTI* FROM GROOTE EYLANDT NT AUSTRALIA 2006-2008

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INTRODUCTION

Medical Entomology (ME) of the NT Department Health and Families (DHF) operates an exotic mosquito surveillance program in the NT to detect the possible importation or establishment of exotic mosquitoes, particularly the *Aedes* vectors of dengue (Whelan 2007). This surveillance is aimed particularly at ports that are visited by overseas vessels, which includes Alyangula (lat 13.85S, long 136.42E) on Groote Eylandt in the Gulf of Carpentaria in the Northern Territory (NT) of Australia.

On 31 October 2006, larvae of the dengue mosquito *Aedes (Stegomyia) aegypti* (Linnaeus) were identified from an ovitrap collected in the port area of Alyangula. This indicated a possible on-shore establishment of this species via a vessel from overseas or Queensland, and thus posed a threat to the dengue vector free status of the NT (Whelan 1991, Whelan 2007). The detection initiated a survey by the DHF to determine if there was any establishment, and if elimination measures were required.

Dengue, a viral disease of humans, is an increasing public health problem in tropical regions of the world, with large outbreaks involving many thousands of cases and many deaths in various tropical countries to the north of Australia (Gubler 1998**).** Although dengue is not endemic in Australia, the principal vector of this disease, *Ae. aegypti,* is established in North Queensland, where importation of the virus in infected travelers leads to regular outbreaks of dengue disease (Russell and Kay 2004).

Aedes aegypti was widely established in the NT in the 1940's where it was recorded from many of the towns in the northern half of the NT, including Darwin the principal city on the north coast, as well as inland towns including Pine Creek, Katherine, Mataranka and Larrimah, with the most southern extension at Anthony's Lagoon and Newcastle Waters (O'Gower 1958). Its main distribution closely followed roads and railways (Lee et al.. 1987). There was a decline in distribution after 1946, with a probable absence from Darwin in 1953 (O'Gower 1956), but remained established in some locations until at least 1956 (O'Gower 1958, Lee et al. 1987).

Aedes aegypti disappeared in the NT some time between 1956 and1974, with no widespread surveys or records of its presence in the intervening period. The decline and disappearance is thought to be the result of a contribution of various factors, with the most important being the widespread reticulation of water during and soon after World War 2 and the coincidental removal of rainwater tanks (O'Gower 1956, O'Gower 1958, Lee et al. 1987).

In 1974 regular mosquito larval surveys, human biting collections, and light trapping were started in Darwin by ME. These surveys and collections were extended and intensified over the following years to include ovi-traps around overseas arrival ports and airports, regular CO_2 baited light-trapping (EVS traps) in principal towns, and widespread larval surveys of most towns and communities. This included a specific program to detect exotic receptacle breeding mosquito species (Whelan 2007). All of these efforts failed to detect *Ae. aegypti* established in any location in the NT from 1974 to 2004, when an incursion was detected in Tennant Creek and was subsequently eradicated (Whelan et al. 2004, 2005; Whelan 2007).

The NT is particularly vulnerable to the reintroduction of the dengue mosquito from overseas. There have been numerous interceptions of *Ae. aegypti* larvae on overseas vessels and cargo in the Darwin Port area by the Australian Quarantine Inspection Service (AQIS) (Whelan 1998, Whelan and Tucker 1998, Whelan et al. 2001a), with a number of detections of pupae, fresh pupal skins, flying adults, or detections in ovitraps, indicating risk importations with a possibility of on shore establishment (Whelan 1981, Whelan et al. 2001a). After each risk importation, thorough survey and elimination procedures were undertaken by ME and AQIS, including adult mosquito fogging by ULV vehicle mounted foggers, intensive receptacle surveys, EVS trapping, and the precautionary treatment of all potential water-holding receptacles with residual insecticides. These were followed by intensive receptacle surveys and EVS trapping after the next rain event to ensure the success of the elimination measures (Whelan et al. 2001b, Whelan et al. 2003). None of these importations from 1974 to 2004 has previously resulted in any subsequent on-shore establishment of this species.

The NT is also vulnerable to the importation of *Ae. aegypti* from North Queensland. An incursion of *Ae. aegypti* into Tennant Creek in 2004, during the building of the Alice Springs to Darwin railway project, was eradicated in 2006 after an intensive program by ME (Kulbac and Whelan 2007, Whelan 2007). DNA analysis of these mosquitoes indicated the incursion was imported from North Queensland, probably as eggs in dry receptacles from Cairns by vehicle transport (Beebe et al. 2005). The widespread occurrence of *Ae. aegypti* in coastal Qld, particularly coastal islands such as Mornington Island near the NT border (Sinclair 1992), means that the NT is also vulnerable to the transport of this species by vessels to towns and communities not covered by AQIS surveillance.

In addition, the NT is very receptive to receptacle breeding mosquitoes. There are relatively high populations of receptacle breeding species such as *Aedes notoscriptus* and *Aedes tremulus* detected by regular EVS trapping in various towns and communities across the north coast of the NT (ME annual reports 2000 to 2007). Ovitrap results from residential and industrial areas in the major towns indicate year-long breeding, with seasonal peaks in the wet season (ME annual reports 2005-08). Receptacle surveys of various towns and communities indicate a relatively high number of receptacles per premise breeding endemic mosquitoes (ME annual reports) and underground sites are prevalent (Lamche and Whelan 2003). Port areas are particularly receptive. During surveillance and elimination procedures around port areas, relatively high numbers of adult *Ae. notoscriptus* have been recovered from EVS traps, and there have been numerous receptacles with water and *Ae. notoscriptus* larvae (Lamche et al. 2004, Nguyen and Whelan 2007).

Groote Eylandt, located in the Gulf of Carpentaria approximately 50 km off the east coast of Arnhem Land in the Northern Territory, is Australia's third largest island (2258 sq km) (Fig 1).

Figure 1. Groote Eylandt

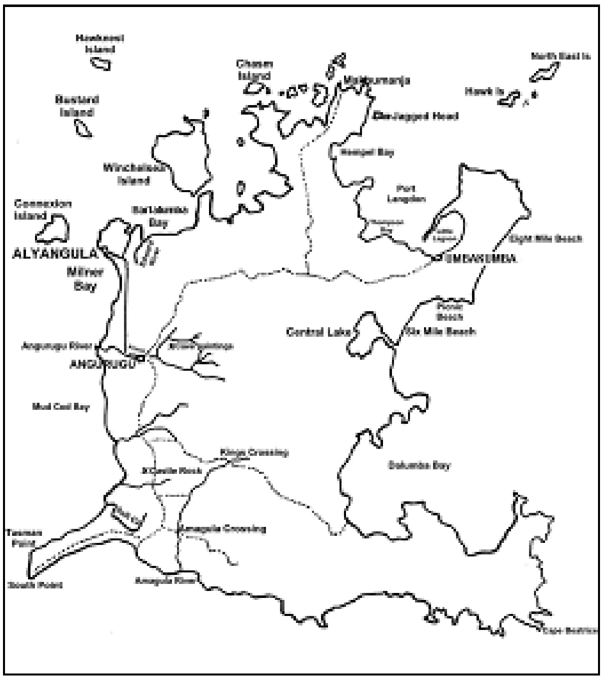

Figure 2. - Groote Eylandt

The island has a monsoonal climate with an average rainfall of 1009 mm falling mainly between December and April (BOM 2008). The mining town of Alyangula is the largest town on the island. The traditional owners of the island are the Anindilyakwa people and there are a number of Aboriginal communities on the island, with the largest, Angurugu located near the airport, and Umbakumba in the northeast corner (Fig 2). There are also smaller communities on nearby islands and the mainland that have connections to Groote Eylandt by plane and small vessels such as dinghies.

A large manganese ore deposit in the western portion of the island is mined by the Groote Eylandt Mining Company Pty Ltd (GEMCO), and regular overseas shipments of ore are loaded at the port located near Alyangula. Other vessel arrivals include a regular coastal barge from Darwin. Alyangula is a residential town of approximately 400 properties which house or support 1400 people who are mainly GEMCO employees or support services. Most of the houses are elevated on piers with approximately 800sq m. yards. Underneath the houses are used as storage areas and have sheltered washbasin areas that are ideal as mosquito harbourage areas. Many houses store dinghies and larger boats in the open where they are potential water holding receptacles.

The detection of *Ae. aegypti* on Groote Eylandt initiated an immediate survey and control operation by ME to determine if the species was established in the Alyangula port area or the town, and to eliminate any possible on-shore establishment. This report details the methods and results of the *Ae. aegypti* surveillance and eradication and enhanced activities carried out on Groote Eylandt and other nearby areas in the NT between 2006 and 2008 under the Groote Eylandt *Aedes aegypti* Eradication Project.

METHODS

Detection and initial actions

The routine exotic vector surveillance program on Groote used three ovitraps set fortnightly, at the airport near Angurugu, the port area, and in the residential area of Alyangula. This surveillance was supplemented by three fortnightly CO_2 baited Encephalitis Vector Surveillance (EVS) traps (Rohe and Fall 1979) set at the mine site near Angurugu, in Alyangula at the port area and on the golf course, as well as periodic receptacle surveys and complaint investigations, as part of a routine endemic mosquito monitoring program.

After the detection, ME immediately informed AQIS, and checks were made of recent overseas vessels arriving in Alyangula to determine a possible mode of importation. ME also deployed an initial survey and control team to Groote Eylandt in the week following the detection to determine if there was an establishment, to what extent, and to carry out an emergency control program to limit the possible spread within the port area and to other areas on Groote.

The initial survey on 6-9 November 2006 by ME indicated that *Ae. aegypti* was established and widespread in urban Alyangula, and that a full-scale survey and eradication program was required in Alyangula, and that an extensive survey was required for the rest of Groote Eylandt and other island and mainland connections to determine a possible source or spread. DHF immediately advised the Commonwealth Department of Health and Ageing (DOHA) as part of standing exotic vector detection arrangements, and sought 'in-principle' funding assistance. Specimens of *Ae. aegypti* from Groote were submitted to Dr Nigel Beebe for DNA analysis to determine their possible origin.

Increased surveillance and plans for control activities consistent with a protocol for action for a risk importation of an exotic vector (NAMAC 2005) were outlined for joint AQIS and DHF action.

The recommended measures included;

- Checking and treating all potential artificial receptacles on vessel cargo going from Groote Eylandt to Gove and any other NT ports.
- Strengthening exotic mosquito surveillance measures at Groote Eylandt and Gove port and airport areas.
- Receptacle surveys around Groote Eylandt, Gove, and other nearby coastal communities, to determine the extent of the establishment.
- Public announcements of the incursion, and requests for public assistance in preventing the movement of all receptacles or spraying/treating all receptacles likely to be moved from Groote Eylandt, including dinghies and recreation boats.
- Checking all vessels, including trawlers and private dinghies, for water holding receptacles, and spraying/treating all receptacles on vessels arriving in other NT ports that originated from Groote Eylandt.
- A receptacle inspection and spray treatment/eradication program in Alyangula to be implemented as soon as possible during the wet season of 2006/07.

Plans were formulated for an eradication program using the methods and protocols used in the Tennant Creek eradication program (NAMAC 2005, Whelan et al. 2005, Kulbac and Whelan 2007). The plan called for a 2 year program by a task dedicated team to carry out all survey and treatment operations on Groote and nearby mainland and island communities. The eradication plan was outlined to National Arbovirus and Malaria Advisory Committee (Commonwealth Department of Health and Ageing) members, who supported the principle to eradicate the incursion. The main element of the plan was for repeated receptacle surveys to determine the location of all actual and potential receptacles, and the treatment of these receptacles with a residual insecticide or chlorine. Adult surveillance was to be primarily by CO_2 baited EVS traps supplemented by other specialized traps. Inspection and rectification of infrastructure including drain larval surveys, rectification of drains, and removal of mosquito breeding sites was to be an integral part of the plan. There was a standard protocol for premise entry, surveys and treatments, with a standardized data recording system. Media alerts and community communication and participation was an important element in the plan.

Assistance was sought from GEMCO for logistics, accommodation, and approvals for access by ME staff to inspect company houses, wharf and mine areas, and the application of insecticides in these areas. ME also sought approval from the NT Chief Health Officer and GEMCO for information on all recently relocated Alyangula residents to other parts of the NT to enable surveys of their new residences and possible treatment of any receptacles relocated from Groote Eylandt. The NT Minister of Health discussed the situation with senior NT health officials and DOHA representatives in a teleconference in Darwin on 6 December 2006, and requested funding assistance from DOHA. The detailed plan and a proposed budget were subsequently submitted to DOHA with a formal request for funding assistance.

ME proceeded to implement the eradication plan with bridge funding from DHF and personnel comprised of ME and other DHF staff and volunteers. The eradication operation started in the week 13-17 November 2006 with the interim team of 6 conducting surveys and control activities at the transport link sites of the airport and port areas, and in Alyangula township. The eradication program was conducted by the interim team from the first week of the program until early February 2007. A Project Manager was appointed on 30 November 2006 to assist the Project Director (senior medical entomologist ME) to manage the recruitment and training of project staff under the NT Public Service system, the provision of equipment and supplies, organisation of travel, office/laboratory space, and the leasing of vehicles.

The other 5 project staff commenced duty progressively from February to March 07 and initially commenced a pesticide operators training program. Staff were also trained in specific insecticide application, mosquito survey, and mosquito identification techniques, with much of the survey and control training carried out on the job with ME staff on Groote Eylandt. Both the interim team and the project team conducted the program on fly-in fly-out weekends to Darwin operation, with project staff progressively spelled in Darwin after three or four weeks, and their places supplemented by ME staff. Other logistic, personnel and operational support was provided by GEMCO and the NT Government.

Maps

Operational maps were prepared of all towns and communities on Groote Eylandt to aid in the location and recording of all data in the survey and control operations. The NT cadastre (mga_52_gda94) was used with GIS software to determine property information (lot numbers, street numbers, and XY coordinates) in all communities other than Alyangula. The cadastre was also used to produce printouts showing property outlines, their lot numbers and points of interest for use in planning and field operations. Aerial photography from the NT Government and satellite imagery was used as an aid for operational planning and field operations. Property information for Aboriginal communities was obtained from the 'Bush Telegraph' section of the NT Government intranet site that provided links to BAMS (Building Assets Maintenance System) and SLAP (Serviced Land Availability Program) maps. The geographical position of each property in Alyangula (XY coordinates in GDA94 datum) were pre-entered into both the ME Excel spreadsheet of property inspections and the ME insect identifications database, so that this information could be readily extracted for any subset of the data (eg *Ae. aegypti* + ve properties or EVS trap locations) and visualised using a GIS application.

Data recording

Initially, hard copy record sheets of individual lots were used to record all data of inspections and treatments of all lots. Electronic data collection was introduced in July 07 using Palm Personal Computers (PPC) for the collection of data from surveys. HP iPAQ Palm Personal Computers were programmed with Sprint DB Pro access software and forms produced to suit information needs. Where possible, tick boxes and scroll-down boxes were utilised for ease of use. Information was grouped to forms as follows:

- Home: House number, street name, inspector's names, property type and date.
- Access: Entry yes/no, owner home or not, inside inspected or not, dog present and it's character, reason for no entry.
- Roof gutter: Presence/absence of a gutter, the gutter condition and the type of gutter treatment applied. Follow up inspection required?
- Revisit: Is the survey a revisit (yes/no), the inspector name, the revisit date and a comments box.
- Receptacle: Total dry receptacle, total wet receptacle and a general comment box
- Items: Description of receptacles found and type of treatment applied.
- Vial: Sample number, description of breeding receptacle, water volume, location of breeding receptacle (inside/outside), the number of larvae captured per dip and the type of treatment applied.

The data collected on PPC was downloaded to the main computer storage system as an Excel spreadsheet. Recording of data on PPC required marginally more time to record information than on hard copy. However, the time needed to process data was reduced by 75% compared with manual data processing. Feedback from field staff indicated an overwhelming preference for PPC compared with hard copy data sheets and clipboards.

Adult mosquito surveillance

In Alyangula, the routine EVS trapping at the three sites was continued throughout the project period. In the few weeks after the detection, 8 additional EVS traps were set at 4 ad-hoc locations in the residential areas of the town. However, problems with dry ice restricted EVS trapping, such that trapping at ad-hoc locations was not resumed until the last quarter 2007, but it was intensified in the first quarter of 2008 when CO_2 was supplied by direct feed from a gas bottle using gas regulators and plastic tubing. During January to March 08, ad-hoc EVS trapping for endemic receptacle breeding *Aedes* species was used to target properties for receptacle breeding site surveys. The property location of the trap and surrounding properties were then surveyed and the potential breeding sites found were treated. The ad-hoc traps were placed near buildings where people were living, away from light, and out of exposed conditions. The traps were placed before sundown and collected the next morning. All adult mosquito specimens collected during this project were initially identified in the temporary laboratory at Alyangula using basic field keys, and then forwarded to ME in Darwin for confirmation using specialized keys (Huang 1972, Lee et al. 1987) and data entry. Representative specimens of mosquito adults were pinned and lodged in the MEB reference collection.

Ovitraps (Reiter et al. 1991) consisted of black plastic 2-litre buckets containing water and a "Masonite"™ paddle. The three routine ovitraps were continued each fortnight in Groote during the project period. Additional ad-hoc ovitraps were only used in the verification stage during the latter part of the project due to personnel limitations during the first part of the program. There were three rounds of ovitrapping between 31st January and 13th March 2008, with some traps set in the port/industrial area, and most in the residential areas of Alyangula. In the first round from 30/1/08 to 7/2/08, paddles were collected and replaced after one week due to uncertainty in possible dates of return. After round 1, all traps had methoprene pellets added. In the second round from 7/2/08 to 27/2/08, traps remained in the field for 3 weeks because of inability to return during week 2 due to the lack of accommodation on Groote. During round 3 from 28/2/08 to 14/03/08 traps were collected after 2 weeks for the final collection. The ovitraps were inspected for larvae, with any larvae preserved in labeled vials with 70% alcohol. Larvae and air-dried egg paddles are sent to ME in Darwin for identification and rearing of any eggs to 4th instar larvae.

Sticky ovitraps (Ritchie et al. 2003) consisted of a 2-litre black plastic bucket (diameter 15cm, depth 12cm), and a piece of transparent plastic sheet with insect tack gel on one side positioned on the inside of the bucket. The sticky trap also contained a half lucerne pellet and two S-methoprene pellets. They were covered with plastic bird mesh (1cm aperture) to exclude animals such as frogs, and filled with aged tap water to within 2cm of the rim. Sixteen sticky traps were placed throughout the Alyangula residential area on 8/10/07 and collected 10 days later.

Lethal ovitraps (Williams et al. 2007) were black plastic buckets constructed and operated similarly to the sticky ovitraps, with a strip of bifenthrin impregnated red velour cloth draped lengthways over its rim inside the bucket. The cloth strip (80mm x 150mm) was prepared by soaking it in a solution of bifenthrin (12.5mL/L) and drying it flat on a sheet of plastic sheet in the shade (Williams et al. 2007). A total of 22 lethal ovitraps was set in ad-hoc locations around suburban Alyangula on 28/6/07 and collected on 30/7/07.

Biogents (BG) traps (Williams et al. 2006) are visual traps to lure and trap adult mosquitoes into a catching container with the aid of a suction fan. Four BG traps without olfactory attractants were set during the day on the 11/10/07 and collected the following morning.

Receptacle surveys Alyangula

The principal larval mosquito surveillance method used was the receptacle survey. Receptacle field teams generally consisted of two or three members. Permission was sought from each property occupant before property examinations and the project was explained, with project literature dispensed to each occupant.

The initial survey and control operation covered the port/industrial area and the airport to ensure transport modes were the first to be surveyed and treated. Urban Alyangula was next in priority, with each property or parcel of land, including vacant lots, inspected for any receptacles capable of holding water. All receptacles were recorded for the presence or evidence of water, and any larvae were sampled into labelled vials. Stainless steel ladles (well diameter 12cm, well depth 4.5cm painted white on the inside) were used to examine water samples for larvae from most receptacle types. Disposable 5mL plastic pipettes were used to collect mosquito larvae from the ladle or small receptacles and transfer them to the specimen vial. Turkey basters and sieves were used to sample larger receptacles or murky water. All larvae were collected from small receptacles. For larger receptacles, a sample of as many larvae as possible within a short period was taken, ensuring different looking larvae and instars were included in the sample.

Each vial was labelled to indicate the collector, date, town and a unique property lot number. Receptacle information including description, approximate volume of water, number of larvae, treatment, and property details including date, property lot, property location, street name, collector, and inspection observations and findings were recorded on a property inspection form. Information from the forms was later entered into an Excel spreadsheet. Details of mosquito samples were also entered into the ME Access database of all mosquito collections for the NT. The water in the sample vial was replaced with 70% alcohol as soon as practicable after collection (usually within three hours) for preservation. Initial identification was done on Groote Eylandt in the temporary laboratory area, with identifications done daily. All mosquito larvae were then sent to the ME laboratory in Darwin for identification confirmation (Huang1972). Representative specimens of larvae were lodged in the ME reference collection. Larval of *Ae. aegypti* preserved in 70% alcohol were sent for genetic analysis (Beebe et al. 2005).

During the wet season of 2006-07 there were 3 repeated rounds of inspection and treatment in Alyangula, including the residential area, the port area, and the industrial areas. In the dry season months of 2007, the eradication teams focused on Alyangula. Surveys were systematic through the properties, with later additional ad-hoc surveys around prospective properties in Alyangula, based on the results of either the presence of *Ae. aegypti* or the presence of endemic *Aedes* species in receptacles or EVS traps.

During the wet season of 2007-08 two complete rounds of survey and control were carried out in Alyangula. In addition, a last stage focused survey and control operation was carried out during February to March 2008 in the Alyangula residential area and the port-industrial area to confirm the elimination. This receptacle survey was focused around properties close to detections of endemic receptacle breeding *Ae*. species in the EVS traps, ovitraps or receptacles.

Receptacle surveys other areas/communities

The other major areas/communities on Groote Eylandt included Angurugu (169 properties) and Umbakumba (67 properties), and the Alyangula port industrial area (30 properties). There was also a number of smaller communities and outstations, which ranged from 2 to 10 properties. Two or three surveys and treatment rounds were conducted at the mine site, the other major communities on Groote Eylandt, and at Bickerton Island and Numbulwar on the mainland. From one to three rounds were also conducted in the minor communities on Groote Eylandt.

Bickerton Island and Numbulwar are 2 communities located relatively close to Groote Eylandt. These communities have regular barge and private dinghy sea connections to Groote Eylandt and were possible sources or destinations where *Ae. aegypti* could be transported to or from Alyangula. Both communities were visited twice by the eradication team. There were some minor outstations on Groote Eylandt with very few or no people and were relatively inaccessible. They were deemed as having little likelihood of being or remaining foci of infestation.

The inspection/treatment rounds included;

Alyangula port/industrial	7 rounds
Angurugu (Groote Eylandt)	5 rounds
Mine site Angurugu area. (Groote Eylandt)	4 rounds
Umbakumba (Groote Eylandt)	3 rounds
Malkala (Groote Eylandt)	4 rounds
Bartalumba Bay (Groote Eylandt)	5 rounds
Dugong Beach Resort (Groote Eylandt)	4 rounds
GEBIE Development (Groote Eylandt)	3 rounds
Ndunga (Groote Eylandt)	2 rounds
Emerald River (Groote Eylandt)	4 rounds
Bickerton Island.	3 rounds
Numbulwar (mainland)	2 rounds

Receptacles Treatment

Actual and potential *Ae. aegypti* receptacle breeding sites were treated with one of the residual insecticides or chlorine (Ritchie 2001, WHO 2005). The residual insecticides used bifenthrin (Brigade ai 80g/l), lambda-cyhalothrin (Demand ai 25g/l), alpha-cypermethrin (Bestox ai 50g/l), S-methoprene (Prolink pellets ai 40g/kg or Prolink briquettes ai 18g/kg). The chlorine treatments used liquid household bleach 10% ai undiluted and mixed with 40mls per litre dishwashing detergent (Sherman et al. 1998). All actual breeding receptacles were treated with chlorine using a 7 litre pressure sprayer or a 1L household spray bottle, left for 5-10 minutes, and then rinsed before treating with a residual synthetic pyrethroid insecticide. Initially and until mid January 2007, bifenthrin was used in routine receptacle treatment, until it became clear this insecticide was not lasting more than two weeks as a larvicide. From mid January 2007 to mid June 2007 lambda-cyhalothrin was used routinely in receptacles until mid June 2007 when it was relaced by alpha-cypermethrin.

Many domestic sites that were likely to harbour adult dengue mosquitoes, such as downstairs washbasin areas, piles of rubbish and palm fronds, and shrub areas close to houses were treated with bifenthrin. The synthetic pyrethroid insecticides were diluted with water at label rates, with bifenthrin at 12.5mL/L, alpha-cypermethrin at 16mL/L, and lambda-cyhalothrin at 16mL/L, and applied using a hand-held garden pressure sprayer (7L Solo or Hardie plastic sprayers). The sprayers were conveyed in the field with small 2-wheeled trolleys.

Receptacles used for pet or human food, water consumption, or recreation, were treated with bleach to ensure any eggs on the inside of the receptacle were destroyed. Water found in tanks, boats or other large receptacles that could not be drained were treated around the waterline with a residual insecticide and additionally treated with methoprene pellets or briquettes.

Receptacles that were used to hold water or food for animal consumption were treated only with bleach or S-methoprene pellets. S-methoprene pellets were dispensed by hand and were routinely placed in any receptacle that held or could hold water, including house roof guttering.

Infrastructure inspections and treatment

Road stormwater drains in Alyangula had localised pooling of water in both the underground concrete drain sections and their associated side entry pits. Insecticide treatment of the underground system was done once in December 2006 by flushing 40L of liquid temephos (Abate 100E) at the lable rate into the side entry pits upstream of pooling in the sub-surface drains. Sediment, both inside the pipes and at outlets at their discharge points, was the main cause of ponding in the pipes. The sediment inside the pipes could not be cleared because of the fragile condition of the corrugated iron linings. A street sweeper did regular circuits of the town to reduce silt inputs during early 2008 and all the sediment inside entry pits was pumped out. Drain outlets were excavated to facilitate flow out of the pipe into unlined open earth drains between late January and the end of February 2008.

Road side-entry pits in Alyangula were treated on the 8-9 October 2007 with S-methoprene briquettes, and the interiors were sprayed with bifenthrin. Bifenthrin was sprayed on all surfaces within the pit, except the base, until just before the point of run-off. Single S-methoprene briquettes were enclosed with a small square of styro foam in plastic mesh with cable ties. The enclosed briquette was placed into the deepest section of the pit and attached to the top of the side entry pit with fishing line.

Following experiences in Queensland (Kay et al. 2000, Russell et al. 2002), Telstra pits and manholes were surveyed and treated from 9-11 October 2007. A Telstra employee accompanied the eradication team to enable the treatment of 223 Telstra pits in Alyangula. Pit lids were removed by the Telstra employee to allow the treatment similar to that in side entry pits above. During the treatment of the Telstra pits, 17 of the concrete lids were found to be damaged and were replaced by Telstra. Water valve and electricity system manholes were inspected between 9 -11 October 2007, and samples were taken of any larvae. The 243 water/electricity pits were opened by a staff member of Delta FM, a subsidiary of the GEMCO general maintenance group. All pits were treated with briquettes and sprayed with alpha-cypermethrin. An unsealed septic tank was treated with briquettes and alpha-cypermethrin, and the concrete lid re-positioned and sealed.

House roof gutters were not inspected for larvae because of the occupational health and safety issues. All roof gutters were treated with S-methoprene pellets thrown by hand from below. The Alyangula Town Management crew worked systematically through the town altering/removing/fixing house roof gutters**.** The replacement and repair of house gutters was continuing at the completion of the field project in 2008.

The Alyangula town dump was surveyed for receptacles and treated with insecticide during round 1. The dump initially consisted of multiple dumping areas, more than 800m of unconsolidated active tip face to a height of four meters in some areas, and large numbers of available receptacles. The dump was rehabilitated by GEMCO by establishing a single deep pit with rubbish covered regularly with soil.

A general clean-up operation of the township was undertaken soon after the dengue day public relations program, to minimise water-bearing receptacles able to provide breeding locations. GEMCO provided staff and trucks for removal of articles left for disposal on household yard verges. The rubbish items were taken to the tip after collection and covered with soil as part of the normal dump management.

Publicity and media

Soon after *Ae. aegypti* was detected, public notices were placed in the NT News and the local Groote newspaper "eylandt echo" outlining the detection, the need to carry out surveys for larvae, and seeking cooperation from the public to remove or store receptacles, and to prevent movement of receptacles from the island. Notices of the field survey and control operations were placed on local notice boards, and in health clinics, supermarkets and shop windows. In the first weeks of the initial control period, DHF established a 1800 telephone hotline specifically for enquiries about the *Ae. aegypti* control program. The hotline linked callers to DHF (Centre for Disease Control) staff during the day, and recorded messages at night. Publications and flyers developed by Queensland Health for their dengue mosquito control program, outlining general information on dengue and receptacle breeding places and treatments by householders, were approved by Queensland Health for DHF use and placed in public places.

Alyangula Dengue Mozzie Day (ADMD) was held on Saturday 20th October 2007 to coincide with the early wet season. The ADMD was publicised throughout the Alyangula community, providing information on the dengue mosquito incursion and encouraging residents to discard potential breeding receptacles from their yards prior to the onset of the wet season. ADMD was advertised in the "eylandt echo" newsletter in the six weeks leading up to ADMD. School based activities were included to involve children and parents. The activities included lectures from ME staff, cartoon colouring-in competition, and a poster and essay competition, with prizes presented at the school assembly. A pamphlet-drop in the week immediately prior to ADMD suggested items that should be considered for either disposal or better storage. The pamphlet encouraged residents to clean up their yards and remove potential receptacles prior to the onset of the coming wet season, and secondly acted as a competition entry form to win two return airfares to Darwin. The residents had to tear off this entry form and bring it to the ADMD display to enter the competition.

On ADMD there was a shopping arcade sausage sizzle, publicity displays, promotional giveaways and competitions. Poster boards displayed mosquito life cycles, photographs of common offending receptacles, clinical aspects of dengue disease including coloured photographs of dengue-affected individuals, and other general mosquito related material. There were also static displays of the traps used in the eradication program, and various target receptacles such as clam shells, plant cutting buckets, cans, bottles and plastic bags. All give-away items including pens, rulers, mouse pads, calculators and hats incorporated the message, "Stop the dengue mossie".

RESULTS

EVS traps

The routine EVS traps were set 70 times at the 3 locations in 07/08. Of those receptacle breeding species, the total numbers of *Ae. notoscriptus* recovered for the year were 5 in Alyangula urban and 21 at the golf course trap sites. This compared with the total number *Ae. notoscriptus* recovered in the same three sites in 06/07 of 333 in Alyangula urban and 32 at the golf course.

The first and only EVS trap to recover *Ae. aegypti* was on 9/11/06 from 1 of 3 ad-hoc traps set that week in the Alyangula suburban area. In the fourth quarter 2006 there were only 8 ad-hoc EVS traps set, due to the difficulty in getting dry ice to Groote Eylandt. Ad-hoc trapping was intensified from the last quarter 2007 to the first quarter 2008 with 6 and 47 traps set respectively in the Alyangula area. No EVS trap was positive for *Ae. aegypti* in this verification stage. However in the first quarter 2008, there were recoveries of endemic species, with the number of traps positive including *Ae. notoscriptus* (9), *Cx. quinquefasciatus* (7), *Ae. katherinensis* (1), with no *Ae. tremulus* (0). These recoveries prompted priority receptacle surveys in the positive trap localities.

Ovitraps

Five 3rd and 4th instar *Ae. aegypti* larvae were identified on 31 October 2006 during the routine processing of the fortnightly ovitrap collection from the Alyangula port area on 20 October 2006. The larvae were present in the ovitrap on collection, but were not identified until after the egg paddles were flooded on 29 October and processed for possible eggs. There were no further collections of *Ae. aegypti* from the routine ovitraps on Groote.

Of the 60 ovitraps set in 06/07, 25 were positive, with *Ae. notoscriptus* present 14 times, *Ae. tremulus* present 8 times, and *Ae. katherinensis* 7 times, in addition to the 1 positive for *Ae. aegypti* in the port area. This compared with the 75 routine ovitraps set in 07/08 at the 3 locations, with only 2 positive for mosquitoes including 1 positive for *Ae. notoscriptus* in Alyangula urban and 1 positive for *Ae. katherinensis* at the airport.

A total of 193 ad-hoc ovitraps were set within the Alyangula residential and Alyangula port/industrial areas in the period 30/1/08 to 14/3/08. There were *Ae. aegypti* in these ad-hoc ovitraps. However there were recoveries of endemic species, with the positive ovitraps including *Ae. katherinensis* (25), *Ae. notoscriptus* (15), *Ae. tremulus* (4) and *Cx. quinquefasciatus* (2).

Sticky traps

Of the 16 sticky traps set, 4 had mosquitoes but none were *Ae. aegypti*. This method of surveillance and possible adult removal was discontinued because of the presumed very low population of adult *Ae. aegypti*.

Lethal ovitraps

Of the 22 lethal ovitraps, none were positive for mosquito eggs. This method of surveillance and control was discontinued because of the presumed very low population of adult *Ae. aegypti*.

BG traps

Two BG traps collected on 9/11/06 recovered a single *Ae. aegypti* in one of the traps, together with 1 *Cx. quinquefasciatus*. This method of surveillance was suspended because of the presumed very low population of adult *Ae. aegypti.* However in the latter part of the project during the verification stage from the third quarter 2007 to first quarter 2008, the 4 BG traps recovered no *Ae. aegypti*, 1 *Ae. katherinensis* and 4 *Cx. quinquefasciatus*, as well as other non-receptacle breeding mosquitoes.

Property surveys

There were between 382 and 445 separate properties surveyed and treated in urban Alyangula in the various rounds (Table 1). The difference in the number of properties surveyed was due to various large properties being split into manageable areas for later surveys. The initial receptacle survey established that a population of *Ae. aegypti* was well established in urban Alyangula, with no establishment in the port /industrial area. At the completion of the first round of inspection and treatment of urban Alyangula on 11 December 2006, 50 (11.7%) of the properties were positive for *Ae. aegypti* larvae. In the subsequent rounds 2, 3 and 4, the number of infested properties was reduced to 22 (4.9%), 18 (4.1%) and 1 (0.2 %) respectively (Fig 3). There was no *Ae. aegypti* detected in the subsequent 3 complete rounds or the last targeted survey. None of the other areas/communities on Groote or the mainland was positive for *Ae. aegypti*, except for the one property in Angurugu that was positive in the first round only.

Receptacles breeding

There were 487 receptacles breeding mosquitoes in urban Alyangula over the program, with 132 of these receptacles breeding *Ae. aegypti.* During the first round of inspection and treatment, there were 80 receptacles positive for *Ae. aegypti.* This was reduced to 27, 24 and 1 receptacle in subsequent rounds (Table 1). The last receptacle positive was a tarpaulin in an Alyangula house property on 4 June 2007.

There were 4 other receptacle breeding species recovered in Alyangula. *Culex quinquefasciatus* (304 times) was the most frequent found breeding in receptacles, followed by *Ae. notoscriptus* (91), *Ae. katherinensis* (55) and *Ae. tremulus* (1) (Table 1).

The type of receptacles

The most frequent category of receptacle with *Ae. aegypti* was garden accoutrements (51), followed by domestic commercial usage containers (29), and discarded household containers (22) (Table 2). In the garden accoutrements category, the most frequent types of receptacles were pot plant drip trays, pots and receptacles used to strike plants (38). In the domestic/commercial usage category, the most frequent receptacle type was buckets (22). There were 4 natural receptacles, which included 3 instances of breeding in bromeliads and one in a coconut shell. There were no positive water storage containers such as rainwater tanks, mainly because these receptacles were largely absent in Alyangula.

Species association

There were 14 other species found breeding in receptacles in Alyangula, with 9 of these found in association with *Ae. aegypti.* The most frequently associated species were *Cx. quinquefasciatus* (42 times) followed by *Ae. notoscriptus* (26) and *Ae. katherinensis* (10).

Surveys other communities

Angurugu, which is located approximately 20 km from Alyangula, was the only other community where *Ae. aegypti* larvae were found. The community of Angurugu was found to have a single positive property from a tyre containing *Ae. aegypti* eggs and larvae. A boat located at the same property as the positive tyre had been stored in Alyangula for a number of weeks and had recently been relocated to Angurugu. The boat may have been the mode of transport of *Ae. aegypti* to Angurugu. Results of subsequent surveys/treatment of the community indicated that *Ae. aegypti* did not establish in Angurugu because it was eliminated during the initial survey and treatment. After the first round of survey and treatment in Angurugu, no further communities, apart from Alyangula, were positive for *Ae. aegypti*.

Origin

Checks by AQIS could not implicate any vessel or cargo as having a high probability of importing either larvae or eggs in receptacles or adults flying from a vessel. An analysis of the DNA of *Ae. aegypti* specimens recovered in the program indicated that this incursion was from overseas and was a new strain of *Ae. aegypti* for Australia from an unknown source (Beebe pers. com.).

Publicity and media

The initial receptacle clean up promoted by the media, posters, and public notices was evident in some properties in the town, but overall the response by residents was disappointing. However, in the later stages, the pamphlet drop and competition entry form as part of ADMD was considered successful, with approximately 30% of entry forms coming from the residential pamphlet drop. The involvement of the education department staff was very positive and the competition submissions from students were considered excellent. Poster boards displaying mosquito life cycles, photographs of common offending receptacles and other general mosquito related material were keenly viewed by residents, and provided opportunities for interactive discussion between ME staff and the residents. Many of the hats and pens were seen in Alyangula after ADMD, so it was clear that the message was received widely.

The Alyangula dengue mosquito day was rated as a success by residents and colleagues in terms of promoting awareness of the dengue mosquito incursion, and offering solutions for residents to adopt in their own homes to minimise breeding receptacles. The secondary aim of encouraging residents to dispose of unwanted building materials and other rubbish took longer to be realised. The initial response seemed poor but project field staff indicated a marked improvement in general yard cleanliness in late December and early January 2008.

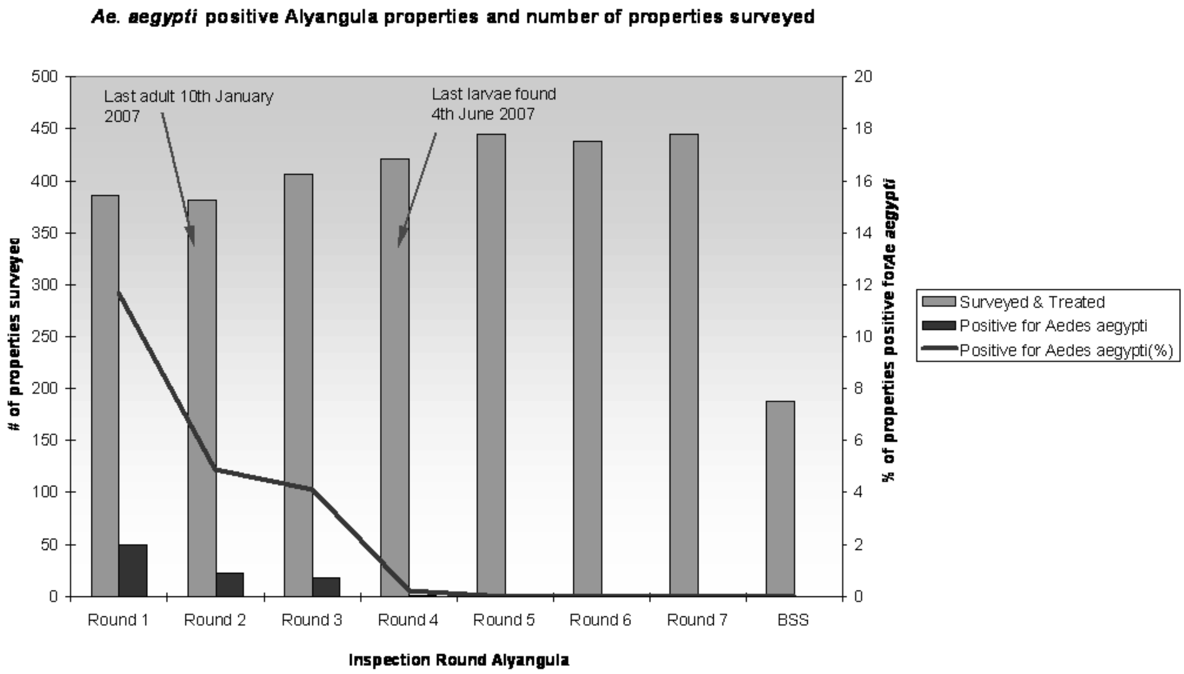

Figure 3. *Ae. aegypti* positive Alyangula properties and number of properties surveyed

Table 1. Number of receptacles with mosquito larvae Alyangula

Period of *Ae. aegypti* control activities	Date Started	Date Finished	Number of properties surveyed for *Ae. aegypti*	Number of properties with mosquito larvae (all species)	Number of receptacles with mosquito larvae (all species)	Number of receptacles positive for larvae					
						Aedes (Stg)aegypti	*Aedes (Stg) katherinensis*	*Aedes (Mac) tremulis*	*Aedes (Fin) notoscriptus*	*Culex (Cux) quinquefasciatus*	Other species
Round 1#	07/11/06	11/12/06	385	97	146	80	4	0	36	71	33
Round 2	18/12/06	19/01/07	382	70	91	27	25	0	21	50	31
Round 3	03/03/07	14/04/07	406	64	83	24	8	0	24	43	25
Round 4	06/05/07	25/06/07	421	31	33	1	0	0	1	31	6
Round 5	03/09/07	27/09/07	445	31	39	0	0	0	0	38	13
Round 6	08/11/07	03/12/07	438	24	26	0	2	0	1	25	4
Round 7	07/01/08	06/02/08	445	37	44	0	15	0	2	30	22
TPBSS[0]	26/02/08	17/03/08	188	20	25	0	1	1	6	16	9
Totals			3110	374	487	132	55	1	91	304	143

[0] TPBSS = Targeted potential Breeding Site Survey

Cost

ME received $582,000 in funding assistance from DOHA in March 2007 for an 18 month program. Expenditure was approximately $50,000 over budget on direct costs, which was absorbed by DHF. In addition to direct costs, there were considerable in-kind and indirect costs provided by DHF for such things as part DHF officer salaries, facilities and equipment, and GEMCO provided direct and indirect assistance with facilities and staff. The expenditures for Dengue day was $2,686 in direct costs for a banner, giveaways, prizes, and the sausage sizzle, with indirect costs of DHF and GEMCO staff time and the use of GEMCO facilities. The total cost of the program was approximately $750,000.

DISCUSSION

The likely mode of transport of the *Ae. aegypti* incursion to Groote Eylandt was as eggs either on freight or rubbish items from a legitimate overseas vessel arriving at Alyangula, or in water storage receptacles from an Illegal Foreign Fishing Vessel (IFFV). However the two common legitimate overseas vessel types arriving in Alyangula were manganese ore vessels, which are usually devoid of water containing receptacles, or coastal barges from Darwin where *Ae. aegypti* is absent. On the other hand there has been an increasing number of IFFVs sighted or intercepted around the NT coast by AQIS or Defense, and there has been recent evidence of IFFV crew coming on shore and leaving water barrels, in addition to storing dried fish and nets (Shortus and Whelan 2006). Consideration of these aspects indicate that the origin of the incursion was most likely from overseas as eggs inside a water storage drum via IFFVs.

The abundance of large private fishing vessels in Alyangula and the habit of fishermen to range widely around the coast suggests a possible mode of transport of *Ae. aegypti* into Alyangula was via a water storage receptacle from an IFFV recovered from a remote location.

Table 2. Receptacle Category Frequency Alyangula

Period	Date started	Date finished	Type and number of receptacles detected with *Ae. aegypti* larvae: Garden Accoutrements	Water Storage Containers	Discarded Household Items	Rubbish	Domestic-Commercial Usage Containers	Recreational	Building Fixtures and Materials	Natural Habitats	Totals
Round 1	07/11/06	11/12/06	35	0	10	5	19	3	5	3	80
Round 2	18/12/06	19/01/07	9	0	6	5	5	0	1	1	27
Round 3	03/03/07	14/04/07	7	0	6	5	4	2	0	0	24
Round 4	06/05/07	25/06/07	0	0	0	0	1	0	0	0	1
Totals			51	0	22	15	29	5	6	4	132

The initial detection in the port area ovitrap appears to have been a coincidence and not related to the entry point of the incursion, as there were no other *Ae. aegypti* found in receptacles in the port/industrial area. It is possible that the port ovitrap was colonised by an adult transported to the port area in a vehicle from urban Alyangula.

The failure of the routine residential ovitrap in Alyangula to first detect the incursion was a cause for concern and demonstrates that multiple numbers of ovitraps are needed in large urban areas in order to have a better probability to detect incursions early. The number of ovitraps in urban Alyangula has now been increased.

The type of receptacles with *Ae. aegypti* present in Alyangula was different from the Tennant Creek experience in one aspect, with no rainwater tanks present in Alyangula. However, even during the mid to late dry season in Groote, when little rain occurred, there were still ample receptacles with water and endemic mosquito larvae, indicating there is no barrier to dry season breeding and survival of *Ae. aegypti* in urban areas in the tropical north. The fact that no recoveries were made from storm drains, side entry pits or Telstra pits indicated a distinct preference for domestic receptacles, and these are the ones that need to be prioritised in any further incursions. The detection of *Ae. aegypti* in bomeliads, pot plant bases and other garden accoutrements indicates a potential mode of spread from one infested community to another when garden items are transferred. Garden accoutrements and natural receptacles should be target receptacles to be banned from movement or treated prior to relocation from infested areas.

The intensified trapping during January-March 2008 with EVS traps and ovitraps showed there were more frequent recoveries of *Ae. notoscriptus* by EVS traps compared with ovitraps, while ovitraps more frequently detected *Ae. katherinensis* and *Ae. tremulus*. Additional untreated receptacles were located after investigations of these detections, which indicates the usefulness of endemic indicator species for locating undetected receptacles in exotic receptacle eradication programs, and the importance of using a number of different surveillance tools for receptacle breeding species.

The steep reduction in the number of receptacles positive for *Ae. aegypti* in the first 4 rounds was the key to achieving success. This result can be attributed to the combined effect of bifenthrin applications to harbourage areas and receptacles, the elimination of eggs in positive receptacles by the chlorine /detergent applications, the location of all breeding receptacles and the removal of larvae, the killing of larvae by the pre-emptive application of lambda–cyhalothrin to every possible dry receptacle, and the use of methoprene in certain receptacles. It is doubtful if elimination could have been achieved with only one of these treatments. This is a key lesson for other elimination programs, such as the current one to eliminate *Ae. albopictus* in the Torres Strait.

Other key reasons why eradication was achieved included the very rapid field response by DHF, the dedicated and experienced staff of ME, the importance of the availability of other DHF staff and volunteers, and particularly the dedication and application of the project staff, combined with assistance from GEMCO and the people of Groote Eylandt.

There were some problems in the program, the chief being the lack of a mechanism for the inspection and treatment of cargo and vessels leaving Alyangula for other Groote communities or the mainland in order to prevent the spread of the infestation to other areas. As the quarantine services only take responsibility for exotic vector exclusion from the first port of call in Australia (Russell 1998), other remote and border areas remain vulnerable. The other problem was staff accommodation, which was overcome by staff experiencing considerable disruption and substandard accommodation. There is a need for a national approach to this problem by having a dedicated or available vessel able to provide accommodation and research facilities with the flexibility to operate in remote localities at short notice. Another potential problem is the significant cost to front line jurisdictions like the NT, who are the gatekeepers for exotic pests or vectors for the rest of Australia. There is a need for available national funding for an initial rapid response and appropriate sharing of costs by other states and the Commonwealth for these front line jurisdictions.

If the incursion had not been eliminated, *Ae. aegypti* would be firmly established in Alyangula, and would have soon spread to other Groote locations, and then to the mainland including Darwin. This would inevitably lead to large outbreaks of dengue, with considerable impacts on the health of the population, as well as an appreciable disruption to tourism and industry. There would also be dengue virus movement to Qld, leading to second front outbreaks of dengue in north Qld, which would jeopardise the present Qld dengue control strategy (Russell and Kay 2004).

The eradication of *Ae. aegypti* from Groote Eylandt was formally declared completed on the 5th April 2008, a little over two years after it was first detected. It has not been subsequently detected anywhere on Groote Eylandt or elsewhere in the NT. This is the second successful attempt to eradicate an established mosquito species in Australia (Whelan et al. 2005), and the first in the higher rainfall tropical region of Australia.

The *Ae. aegypti* elimination on Groote Eyland has been largely a top down approach. Although community involvment played a part in receptacle reduction, a bottom up approach could never have succeed by itself, and the Groote experience supports the idea that, at least in certain instances, there needs to be a combination of both approaches (Gubler 1989).

There have been very few reported successful attempts to eradicate established populations of *Ae. aegypti* in any area of the world (Gubler 1989, Gubler 1998). One of these was the highly successful, vertically structured paramilitary eradication campaign directed by the Pan American Sanitary Board from 1946 to 1970 (Schliessmann and Calheiros 1974) which resulted in the elimination of *Ae. aegypti* from a number of countries in South America. The second was also a rigorous, top-down, military-like vector control operation in Cuba in the 1980s that was based on intensive insecticidal treatment, followed by the reduction of available larval habitats (source reduction), which eliminated the vector from large areas of Cuba (Gubler 1989, Kouri et al. 1989). Neither of these programs, however, was sustainable in the longer term. The other success was in Singapore with a pilot project in a limited area around the airport (Chan 1972). Attempts in other areas of Singapore starting in 1973 only reduced the vector to low levels (~2% premise incidence), which achieved a 15 year low dengue incidence but could not achieve vector eradication (Ooi et al. 2006). More recently there have been reports of vector elimination in villages and communes in Vietnam with community based progams using *Mesocyclops*, fish and sanitation (Kay et al. 2002), and these show promise of sustainability.

The elimination reported here, and the NT exotic vector program, is an example of one of the very few successful programs in the world able to maintain an *Ae. aegypti* free status in a demonstrated vulnerable and receptive geographic area for over 30 years. The surveillance and elimination methods described here may have a place in other areas such as Qld, to either reduce the footprint of *Ae. aegypti* or to eliminate it entirely from a geographic area. The NT program has demonstrated that elimination can be sustained over the long term, and is a cost effective approach.

ACKNOWLEDGEMENTS

Eradication team, Myron Kulbac, Darren Bowbridge, Brett Devitt, Bruce Hitchins, Kevin Horig, Colin Smith, George Singh, Geoff Cole, Graham Goodwin, Sam Gualandi. ME staff, Nina Kurucz, Bill Pettit, Nadine Copley, Jane Carter, Huy Nguyen, Tamara Pearce, Alan Warchot, Alan Niscioli, Raelene Whitters**.** CDC staff, Kathleen Hocking. GEMCO staff, Ross McDonald, Lucas Dow, Brian Quinn, Jeff Millgate, Peter Finney. Norforce, Major Dan Gosling, Andy and Pat Gilliland. Anindilyakwa Land Council, Gavin Enever, Petrina Busbridge. Alyangula Area School, Gerry McKeown. Commonwealth DOHA, Phil Wright. National Arbovirus and Malaria Advisory Committee, Dr Scott Ritchie, Prof Richard Russell. GEBIE, Vincent Aviation, Nigel Beebe. The people of Groote Eylandt.

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