Eradication: the only way to control dengue in Australia

Dengue outbreaks have become a regular occurrence in north Queensland, Australia. Since 1995, dengue transmission has occurred every year, with a total of 20 known outbreaks. These have involved all four serotypes and in 2004 resulted in two deaths from dengue haemorrhagic fever (DHF) (McBride 2006). Following the large epidemic of DENV-2 in 1992–93, the Dengue Fever Management Plan (DFMP), which incorporates disease surveillance, mosquito control and health education was launched (http://www.health.qld.gov.au/dengue/default.asp). The DFMP covers the northern half of Queensland, Australia, the only location in Australia where the dengue vector, *Aedes aegypti*, occurs. The DFMP has gone through several updates and has proved highly successful in limiting dengue transmission (Ritchie et al. 2002). But perhaps most telling is that since the DFMP was launched, dengue has never become endemic in Australia despite the occurrence of 20 outbreaks that resulted in 1864 confirmed cases. Indeed, we have eradicated dengue 20 times since the introduction of the DFMP (Table 1).

I know of only a few other dengue control programme that has the explicit goal of eradicating the virus. Most aim to reduce transmission below epidemic levels, perhaps hoping that the virus will eventually burn out due to herd immunity and control efforts. However, I believe that by aiming for eradication, larger outbreaks and endemicity are both avoided, and staff burnout is minimised. This paper describes how we approach dengue eradication, especially from a virus surveillance and vector control point of view.

Disease surveillance: the key to dengue eradication

The Tropical Population Health Network (TPHN) has an active public health component that involves two public health physicians (in Cairns and Townsville), and five public health nurses based in Cairns (two), Townsville, Mackay and Mt Isa. In Australia, dengue is a notifiable disease and any suspected dengue cases are reported to the regional population health centres. Most of these cases are either diagnosed clinically by local GPs, or are tested using ELISA or card tests in local diagnostic labs. However, many of the results are preliminary and subsequent testing by the state diagnostic laboratory at Queensland Health Scientific Services (QHSS) is required to confirm dengue. Dengue can be confirmed by PCR detection of DENV antigen in sera, or by detection of DENV IgM in sera. However, as IgM can remain in the sera for extended periods, a paired convalescent sera that shows a 4X rise in titre is required for confirmation, although highly suspicious cases will be acted on. Finally, some cases are 'epi-linked' – no sera is collected, but the individual presents a good clinical picture and has direct contact (e.g. lives in the same house) with a confirmed dengue case.

The public health nurse (PHN) is critical to the success of dengue disease surveillance. Each potential case is carefully scrutinised by the PHN, who contacts and interviews each potential case and records contact details, travel history, addresses, symptoms, onset, pathology results, and consulting physician details. This information is used to determine the exposure and viraemic periods, and whether the case is locally acquired. Likely addresses where dengue would have been contracted are identified, and any acquaintances who have been ill are noted and contacted. All locations that cases visited while viraemic and where they may have spread dengue are identified (e.g. residence, work place) and the presence of mosquitoes noted. From these data, three critical decisions are made: 1. is the case likely to be dengue? 2. is it locally acquired? 3. is it likely to have spread? Ultimately, all likely or high-risk cases are acted on by vector control staff. However, in many instances, we wait until the case is confirmed by QHSS testing, which is generally speedy and accurate. The key point is that the PHN does this for all suspected cases, and if the interview indicates that case acquaintances may have dengue, they are contacted too. While PHNs are vigilant in the search for any potential dengue case, they are also skilled at recognising false positives.

Finally, the PHN discusses each highly suspicious or confirmed case with vector control staff, usually a medical entomologist. This is a critical element of the programme, particularly when

responding to imported cases. Together, they decide if the case is likely and the risk of further transmission.

Vector control: incessant chase of every case

Each dengue case that is viraemic is investigated for the risk of dengue transmission. Furthermore, significant contact points of the case (such as addresses of employment, school, residence, friends) are also investigated. All at-risk areas are scrutinised for vectors, and then thoroughly treated to kill all *Ae. aegypti* and prevent further production. This involves inspection of yards for mosquito breeding and collection of larvae for identification. Recently, we have begun to deploy 1–2 unbaited BG Sentinel traps (http://www.bg-sentinel.com/en/bg-sentinel.html) for 18–24 hours to measure the relative abundance of adult *Ae. aegypti*. Our research team has determined that these are an excellent method of collecting male and female *Ae. aegypti* (Williams et al. 2006, 2007). For a single dengue case (or contact point), premises within 100 m receive both larval and adult control, with buildings from 100 to 200 m limited to larval control. For larger, multiple-case outbreaks, areas encompassing several city blocks might be targeted. But the important thing is that we attempt to treat all premises and that each contact point is attended to. If an outbreak was truly large, low-risk areas might receive limited or no treatment.

All water-holding containers where *Ae. aegypti* could breed are sampled and treated. Common containers in north Queensland include buckets, tyres, pot-plant bases, tarpaulins, plastic sheeting and other containers on the ground. Elevated sites such as roof gutters and rainwater tanks, and subterranean sites such as wells, sump pits and septic tanks, are also examined and treated. However, these sites are often cryptic or difficult to access, making complete treatment nearly impossible. Mosquito production in containers is controlled by source reduction, i.e. elimination of a breeding site by disposal, turning over, dry storage or destruction, or chemical treatment using pyrethroid-based surface spray or an insect growth regulator (s-methoprene). We generally use s-methoprene pellets, which are easy to apply to elevated sites such as roof gutters by hand, and provide residual control for several weeks.

However, the success of our programme hinges on the rapid and thorough control of adult *Ae. aegypti*, especially potentially older females that might be dengue-infected. From 1995 to 2003, we used interior residual spraying (IRS) to kill adult mosquitoes inside houses. Water-based formulations of synthetic pyrethroids such as deltamethrin and lambda-cyhalothrin were used and were applied to dark resting places, such as under tables and beds, inside wardrobes and behind furniture, using a pump sprayer. Due to the heavy and specialised demands of IRS, in 1999 we formed a specialist unit, the Dengue Action Response Team, which conducted dengue control. The results were spectacular, with a 91% decrease in dengue transmission from 1995–98 to 1999–2002 (Ritchie et al. 2002).

In 2003, Cairns experienced a large, intensive epidemic of DENV-2 (Hanna et al. 2006). The speed of transmission, with nearly 400 cases occurring within a three-month period, was beyond the capacity of the IRS programme. Additionally, the strenuous effort required to carry a 10 kg sprayer and to treat building interiors for days on end resulted in injuries to vector control staff. We also received complaints about the large amount of pesticide that was being used inside premises. Thus, we embarked on the development of a 'lure and kill' (L&K) programme to control dengue mosquitoes. The L&K programme uses traps or killing devices baited with powerful attractants to lure and then kill female *Ae. aegypti*. Following the successes of Zeichner and Perich (1999), we developed a lethal ovitrap (LO) that used infusion to attract gravid *Ae. aegypti*, which were killed when they attempted to oviposit on a cloth strip treated with bifenthrin (Williams et al. 2007b). Using LOs, we could treat an area twice as fast as when using IRS. With L&K, IRS is restricted to the dengue contact point and adjacent premises, reducing pesticide use by 90%.

The new L&K method allows us to treat broad areas rapidly, a key to successful dengue elimination. Furthermore, the lures are effective for several weeks (Williams et al. 2007b) and focus the pesticide on older, gravid females. Reiter (2007) emphasised that *Ae. aegypti* oviposits often,

laying eggs in several containers, and that novel methods should be developed to target this behaviour. We feel that by setting a large network of L&K traps, coupled with source reduction and larviciding, we can eliminate dengue virus while minimising non-target pesticide impact. Since its inauguration in 2004, we have used L&K to help eradicate dengue in seven outbreaks.

Public education: Reducing the background threat

The third component of the DFMP for North Queensland is public education. We use public education to encourage the community to remove mosquito-breeding containers and thus reduce background populations of the vector. Our programme has two main components:

1. Health promotion
2. Media liaison

Health promotion is coordinated by experienced Tropical Public Health Unit (TPHU) health promotion officers, who work closely with TPHU medical entomology staff and others in the organisation to produce social marketing materials in print and electronic media that carry core dengue behavioural messages (e.g. tipping out household dengue breeding sites, using repellent for personal protection) as well as dispelling myths about dengue breeding (e.g. that dengue mosquitoes breed in swamps and creeks). The media messages are based on standard consumer behaviour research techniques and all dengue campaigns are evaluated for their impact on target populations.

Media liaison is driven by experienced media-trained health personnel in TPHU who prepare media releases and other information for the media. As dengue outbreaks (particularly large-scale ones) can be detrimental to a tourism-based economy such as in North Queensland, close, proactive liaison with the media when outbreaks occur is vital to reinforce individual householders' perceptions of the risk of contracting dengue and to stimulate them to take action in their own homes.

A recent addition to this component has been the development of a dengue website (www.health.qld.gov.au/dengue) that carries most of the information about the DFMP as well as dengue outbreak information and locality maps and advice for the general public and health professionals. The website had over 60,000 hits during the Townsville dengue outbreak in 2007. Information on the website can be updated rapidly and also greatly reduces calls from the public and media to TPHU frontline staff during a dengue outbreak.

Bad with the good

Despite the successes of the programme, we have had to tolerate – and fix – several problems created by aggressive vector control. Delay in notification of cases is an intrinsic problem for disease surveillance. Ideally, we want to detect 'patient zero' before any mosquitoes feeding on the person become infectious, around 10 days). Thus, we employ public education and active surveillance to help locate cases. If an outbreak is suspected, vector control staff ask residents if any family members have been ill and request that they contact the PHN. Local physicians are sent letters warning them of the outbreak and requesting them to test for DENV and report any suspicious cases. Also, the public is told to seek medical attention if ill. False-positive dengue tests, especially IgM based tests, can create an immense workload if each case is actioned by the PHN and vector staff. The PHN must be careful to ensure the case is highly suspicious, especially in the winter influenza season. Plastic lethal ovitrap buckets must be retrieved so they do not become breeding sites when the insecticide is exhausted. This requires recording trap locations and dates and then finding and retrieving the buckets. To reduce the logistical problems involved, we are now developing a new biodegradable lethal ovitrap that does not require retrieval of L&K traps. Finally, the old Queensland Health Act required permission from residents before vector control could be conducted at a premises. Thus, it often took several days, with numerous visits seeking residents' approval, before 90% of the premises in a dengue response area could be treated. The new Queensland Health Public Health Act 2005 has improved control by allowing

vector control staff access to properties to inspect and treat breeding sites with methoprene pellets and L&K traps even if no one is home. Thus, we can treat nearly 100% of properties within 1–2 days.

Benefits of an eradication policy

We strive hard to eradicate dengue and to maintain Australia's endemic-free status. There are many benefits to this. Tourism and business conventions are an important aspect of the economy in Cairns, and the large 2003 outbreak led to cancellations of conventions and a probable decrease in tourism. If dengue were endemic, with sporadic large outbreaks, an overall decline in tourism could be expected. Furthermore, a larger proportion of the population would contract dengue, increasing the likelihood of secondary cases and DHF. Indeed, this scenario has played out in the Torres Strait where, after a series of dengue outbreaks in the 1980s and 1990s, an outbreak of DENV-2 in 2004 led to four DHF cases and two deaths (McBride 2005). Finally, endemic dengue would require sustained efforts by vector control staff to prevent large outbreaks. This can result in staff burnout as well as increased use of pesticides, which increases the risk that pesticide resistance will develop in *Ae. aegypti*. At present our staff have the luxury of downtime, which enables them to recharge their batteries and undertake research projects that improve our programme.

Could a dengue eradication policy be employed elsewhere? Certainly it could be attempted. However, in countries where dengue is endemic, it may be logistically impossible to locate every case, obtain a detailed case history and conduct thorough vector control. Indeed, unless both disease surveillance and vector control are able to respectively identify and conduct vector control for most cases within 1–2 weeks of their onset, –the typical length of the extrinsic incubation period of the virus in the mosquito– the virus is likely to spread further. Also, areas that are subject to large numbers of importations, such as Singapore, may find it impossible to eliminate transmission. Smaller geographic areas, such as islands and isolated urban areas, would be most suited to an eradication policy. But clearly, thorough and efficient vector control must be coupled with sophisticated and aggressive disease surveillance to achieve the goal of eradication. This will be the key to using an eradication approach in other areas.

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Table 1. Eradication of dengue viruses in North Queensland, Australia

No.	Year	Location	Dengue serotype	Control method[a]	Confirmed cases	Weeks until eradication
1	1995	Cairns	Dengue 2	IRS	4	14 weeks
2	1996-97	Torres Strait, Cairns	Dengue 2	IRS	208	28 weeks
3	1997-98	Cairns	Dengue 2	IRS	12	11 weeks
4	1997-99	Cairns, Mossman, Port Douglas	Dengue 3	IRS	498	70 weeks
5	2000	Cairns	Dengue 2	IRS	49	6 weeks
6	2001	Townsville	Dengue 2	IRS	9	3 weeks
7	2002	Kuranda	Dengue 2	IRS	21	10 weeks
8	2002	Townsville	Dengue 1	IRS	2	2 weeks
9	2002	Cairns	Dengue 4	IRS	2	3 weeks
10	2003	Cairns	Dengue 1	IRS	3	2 weeks
11	2003	Mareeba	Dengue 1	IRS	1	1 week
12	2003	Cairns	Dengue 2	IRS	5	3 weeks
13	2003-04	Cairns, Townsville, Torres	Dengue 2	IRS	536	69 weeks
14	2003-04	Torres, Cairns	Dengue 2[b]	IRS, L&K	356	41 weeks
15	2004	Torres	Dengue 2	IRS, L&K	1	1 week
16	2005	Torres	Dengue 4	IRS, L&K	56	7 weeks
17	2005	Townsville	Dengue 4	IRS, L&K	18	22 weeks
18	2005-6	Townsville	Dengue 3	IRS, L&K	8	6 weeks
19	2006	Cairns	Dengue 2	L&K	29	18 weeks
20	2007	Townsville	Dengue 3	L&K	46	13 weeks

[a] IRS Interior residual spraying; L&K lure & kill using lethal ovitraps plus IRS in case and adjacent premises (see text for details). All control also includes larval control.

[b] Includes two deaths (McBride 2005).