MOSQUITO CONTROL AND COASTAL DEVELOPMENT: HOW THEY HAVE COEXISTED AND MATURED IN FLORIDA AND AUSTRALIA

DOUGLAS B. CARLSON,1 PAT E. R. DALE,2 NINA KURUCZ,3 PATRICK G. DWYER,4 JON M. KNIGHT,2 PETER I. WHELAN5 AND D. DIANE RICHARDS6

ABSTRACT. The aims of this review were to compare planning for both mosquito control and land use in east-central Florida, USA, and in New South Wales, Queensland, and the Northern Territory, Australia. Saltwater mosquito production in mangroves and salt marsh is the predominant mosquito control concern in all the areas. Urban encroachment towards saltwater mosquito habitats is a problem in both Florida and Australia. In east-central Florida and the Northern Territory, mosquito control is supported by comprehensive source reduction programs, whereas in Queensland and New South Wales, larviciding is the main method of control. The long-term control by source reduction programs reduces vulnerability to mosquito issues as population encroaches towards wetlands, whereas larviciding programs have to respond repeatedly as problems arise. Problems from urban encroachment are exacerbated if mosquito control and land-use planning are not integrated. Further, urban planning that is not informed by mosquito management can lead to increased mosquito problems by inadvertent design or allowing residential development close to mosquito habitats. This increases the need for mosquito control and related resourcing. At the regional level of governance, Florida and the Northern Territory generally have greater integration between planning for development and mosquito control than at the local government level in New South Wales and Queensland, where there is a lack of integration between mosquito agencies and planners. It is concluded that coordination of planning and mosquito control is more effective at higher government levels than at local levels, which have less connectivity between management areas and/or insufficient resources. The lesson is that collaboration can assist in avoiding or resolving conflicts.

KEY WORDS Australia, Florida, land-use planning, source reduction

INTRODUCTION

About a decade ago, Dale et al. (2008) provided an overview and comparison between mosquito control on the east coasts of Florida and Australia, locales with many environmental similarities as they relate to mosquito production. While mosquito control–related topics such as mosquito habitats, legislative frameworks, funding mechanisms, and organizational differences were discussed, it is now timely to examine the impact of expanding human settlement in coastal environments on mosquito control practices and vice versa. The increasing proximity of human settlement to mosquito habitats incurs a cost for mosquito control and a cost to the nearby human population. The community bears the cost of mosquito control as well as the potential risk of mosquito nuisance and mosquitoborne diseases.

This article compares and contrasts the way mosquito control and development have interacted over the years in areas with similar mosquito habitats in east-central Florida and Australia (Figs. 1 and 2). It investigates how mosquito control has accommodated development and the ability of mosquito control programs to react and adapt to the ever-changing dynamic between development interests and mosquito production relative to public health considerations. The aims are to provide a background on the rationale for mosquito control in both areas and to explore planning processes for mosquito management and urban development by analyzing planning for source reduction and development in similar subtropical to tropical environments. Aspects such as permitting, enabling legislation, collaboration among authorities, ownership, and mitigation are covered, with outcomes identifying strengths, weaknesses, and opportunities for improved decision-making. This information will help maximize future sound land-use planning relating to mosquito control and thus reduce mosquito-related risks to human populations.

BACKGROUND

Florida

The development of Florida has been integrally entwined with the creation of mosquito control programs to make the area habitable, especially given that in Florida’s early history, most people moving to Florida chose to live in coastal areas. Prior
to achieving statehood in 1845, a large portion of Florida was known as “Mosquito County.” During congressional debates arguing the wisdom of including the Territory of Florida as a state in the union, it was argued by legislators that it was nothing more than “a swamp full of alligators and mosquitoes” (Patterson 2004).

Mosquito-transmitted diseases played a prominent role in Florida’s early history. In the 1870s and 1880s, outbreaks of yellow fever ravaged Florida’s Panhandle, Jacksonville, Key West, Tampa, Plant City, and Manatee County. In 1888, in Jacksonville, with a population of 26,800 people, the epidemic killed 44, sickened 5,000, and caused 15,000 to flee the city. These outbreaks stimulated the creation of the Florida State Board of Health in 1889, and it was not until 1948 that malaria was eradicated in Florida. The Florida Anti-Mosquito Association was formed in 1923, and 2 years later, through an act of the Florida Legislature, the Indian River Mosquito Control District was created as Florida’s first mosquito control program (Connelly and Carlson 2009). Additional mosquito control programs and development quickly followed. Over the past century, mosquito control offices have carried out work on private property (owned by individuals, corporations, nonprofit trust organizations) and in public areas (federal, state, and local authorities), making for some unique opportunities for cooperation but also at times raising points of contention.

A significant impetus for development along the Indian River Lagoon (IRL; a 156-mile-long [251 km] lagoonal estuary along Florida’s central-east coast; Fig. 1) was the creation of 192 impoundments (totaling approx. 40,000 acres [16,187 ha]) in salt marshes and mangrove swamps to provide mosquito control. This work was undertaken from 1955 to 1970 and effectively and economically reduced salt marsh mosquito populations in 5 counties (Volusia, Brevard, Indian River, St. Lucie, and Martin) (Rey and Kain 1991). This source reduction effort, along with aggressive larviciding and improved adulticiding technologies, helped coastal development thrive from the 1960s to the present as Florida’s population increased from approximately 5 million to 21

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1 The American Mosquito Control Association was founded in 1935.
Fig. 2. Australia areas referenced in the text.
million, and grew at a rate of almost 1.6% between 2016 and 2017 (Statista 2018). Forty-eight of the 63 mosquito control programs in Florida are part of local county government. The remaining 15 are independent taxing districts, which were formed by an act of the legislature and have their own elected board of commissioners who establish the tax rate on property to provide program funding. Florida state government has also provided some funding to supplement relatively small local programs.

**Australia**

In Australia, settlement usually preceded mosquito control. Mosquito control was a response to development and mosquito-related nuisance and disease issues in the eastern states of Queensland (Qld) and New South Wales (NSW) and in response to military concerns in the Northern Territory (NT). Queensland, NSW, and the NT have a combined population of approx. 14 million with a growth rate of 1.6% in 2016 and 2017 (similar to Florida). This led to development pressure in coastal areas, with more than 85% of the Australian population within 50 km of the coast (Clark and Johnston 2016). This is in part a legacy of early migrants arriving by sea from Europe and finding inland settlement was inhibited by the Great Dividing Range. New South Wales was first settled in 1788, and Qld was settled in 1824, as a penal settlement of NSW until separation in 1859. Mosquitoes were numerous, but pest problems mainly emerged from intertidal areas.

All three areas in Australia have Ross River (RRV) and Barmah Forest (BFV) viruses, transmitted by both saltwater and freshwater mosquitoes. Queensland has the highest number of RRV cases in Australia, with over 50% between 1993 and 2017. However, the NT has the highest rate of RRV, with an average of 109/100,000 people between 1993 and 2017 (compared to 44/100,000 in Qld) (Australian Government 2018).

In Qld, in response to increasing mosquito issues in developing coastal areas, mosquito control was one of the first programs formally implemented in 1959. Control was accomplished primarily by distributing larvicides in saltwater larval habitats. Environmental concerns were not seriously considered until the early 1980s, when some local governments were considering alternatives to larvicides. This led to the development of source reduction by “runneling” in Qld and NSW (Hulsman et al. 1989). A runnel is a shallow spoon-shaped structure constructed on a salt marsh following natural patterns of water movement. It allows access for larvivorous fish, flushes larvae from the marsh, and may affect oviposition, thus controlling salt marsh mosquito populations. Mosquito control is compulsory in Qld under the Public Health Act 2005.

In NSW, mosquito control is not mandatory despite the incidence of RRV and BFV, and so many local government areas do not actively do control. An exception is Tweed Shire Council (TSC) in northern NSW, which has a well-developed program. Also, within metropolitan Sydney, mosquito control has been undertaken for over 20 years, carried out by the state government Sydney Olympic Park Authority on an annual basis, to reduce nuisance-biting impacts on residents and recreational activity around the local area (Webb and Russell 1999). Since hosting the 2000 Olympics, the area has rapidly expanded to dramatically increase the residential populations and become one of Sydney’s major destinations for recreational pursuits. However, mosquitoes are an annual problem, given the extensive estuarine wetlands in the local area (Clafin and Webb 2017). Surrounding land use significantly influences adult mosquito abundance and species richness in urban mangroves, and a control program of larvicide applications to estuarine wetlands was undertaken in response to environmental conditions and immature mosquito populations (Webb and Russell 2001). Some other local governments have occasionally taken action in response to severe mosquito/disease issues. However, with the exception of TSC, coordinated approaches with thresholds for initiating control have not been developed. Prior to this, contemporary 19th century accounts for NSW show that mosquito management was often identified as a motivator for large-scale reclamation works of intertidal foreshores around Sydney Harbour, and the Parramatta River and other wetlands were drained. Mosquito control in NSW in the 1920s was described in Bertram (1927). Use of kerosene and diesel in ponds was encouraged to reduce larval survival, and, since its introduction to Australian waters in 1925, localized releases of the plague minnow (Gambusia holbrooki Girard) increased substantially during the 1940s. Currently, native fish are preferred to Gambusia. As an example of early programs in NSW, the need for mosquito control was recognized in 1942 in Newcastle, because of the fear of dengue, which was associated with poorly maintained water tanks. Surveillance, mosquito fish hatcheries, and Gambusia distribution were initiated, as well as regular oiling of street sumps and the reclamation of swampy areas (Le Messurier 2005).

In the NT, mosquito control began during World War II with localized drainage systems for inner city swamps in Darwin. These were established by the Royal Australian Air Force and the Army Malaria Control Unit in an attempt to reduce the malaria risk. Early records also indicate an aerial *Anopheles* mosquito control operation during the war years. After 1949, there was limited control under the municipal inspector of the NT administration, with a small squad carrying out larviciding and fogging in residential areas of Darwin. In 1973, the Medical Entomology unit of the NT Department of Health was created to conduct biting insect surveillance and control. It was partially funded by the Commonwealth National Disease Control Program and replaced in 1988 by the NT
government, which funded NT Disease Control Program.

From 1975 to 1980, engineering measures replaced adult fogging with larval control and source reduction. In 1981, after a report on mosquito production in Darwin (Whelan 1982), the Mosquito Engineering Measures Committee was formed. Subsequent recommendations were accepted by the cabinet in 1983, with specific funding for mosquito engineering and drain maintenance measures to eliminate larval mosquito habitats and establish, upgrade, and maintain stormwater drains on Crown (i.e., public lands), conservation, defense, and council land. This included extensive infilling of borrow pits and the establishment of drainage systems in coastal wetlands in and around Darwin to connect urban stormwater to free-draining tidal areas (Whelan 1989).

Following public complaints in 1989, a Mosquito Control Task Force was set up to examine the salt marsh mosquito control programs. This resulted in the establishment of a Mosquito Control Advisory Committee in 1990 to review program performance and assist with the decision-making process within the existing statutory mosquito management structure.

In summary, in Qld and NSW, source reduction as part of integrated mosquito control was not considered until the late 1980s, prior to the advent of environmental protection legislation. Today, mosquito control is usually managed at the local government level in the states (NSW and Qld) and at a regional level in NT.

PLANNING AND PERMITTING FOR SOURCE REDUCTION PROJECTS

This section addresses the process for planning and obtaining permits, mainly in tidally influenced wetlands or environmentally sensitive areas, to carry out larval inspections or reduce larval habitats. These areas primarily produce nuisance mosquitoes in Florida and both nuisance and disease vectors in eastern and northern Australia.

Florida

Permitting authorities: Prior to the early 1970s, residential and commercial development in environmentally sensitive areas, as well as mosquito control actions, did not require much permitting. For example, the 40,000 acres of impoundments created along Florida’s central-east coast were largely constructed on private lands simply by a handshake between the property owner and the mosquito control program after state approval for each project was granted (J. Beidler, personal communication). When the ecological importance of salt marshes and mangrove swamps was scientifically first documented in the 1960s (Daiber 1986), along with the creation of the U.S. Environmental Protection Agency (EPA) in 1972, development activities and mosquito control projects in these wetlands began to require permits from federal, state, and sometimes local governmental authorities. Necessary federal permits are typically issued by the U.S. Army Corps of Engineers through consultation with the U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration–Fisheries, and EPA. At the state level, for many years, permitting authority for mosquito control projects was held by the Florida Department of Environmental Protection; however, in the 1980s, it was largely transferred to Florida’s 5 water management districts. Local authorities frequently deferred to the federal and state permits, but in some instances, local county permits were also required.

Enabling legislation: Florida Statutes Chapter 388, which governs mosquito control, reads:

It is declared to be the public policy of this state to achieve and maintain such levels of arthropod control as will protect human health and safety and foster the quality of life of the people, promote economic development of the state, and facilitate the enjoyment of its natural attractions by reducing the number of pestiferous and disease-carrying arthropods.

Continued management of mosquito control impoundments as a source reduction technique comes under this policy, as does larviciding and adulticiding.

Cooperation/coordination among authorities: The permitting requirements and processes for permanent mosquito control projects are separate for federal, state, and local authorities. However, there has been interagency input into reviewing projects to ensure that mosquito control and environmental considerations are adequately addressed. For example, the Subcommittee on Managed Marshes (SOMM), which is a legislatively established interagency committee formed in 1983, provides input on projects impacting salt marsh wetlands. While this committee does not have permitting authority, SOMM has guided projects to properly address both the mosquito control and natural resource concerns that these projects have raised (Carlson et al. 1991).

Australia

Permitting authorities: In Qld, when permits are required, it is a state matter, and the permitting agency is usually determined by the jurisdiction of the area to be modified. For example, permits required by local government mosquito control agencies in fish habitats would be issued by a state fisheries agency. In the 1980s, any permits required in Qld were issued by the Department of Primary Industries (Fisheries). However, source reduction by runneling is now classed as “accepted development”
under the recent Qld State Planning Act 2016, and permits are not required.

No permits appear to have been issued in NSW in the 1980s, although there was some source reduction carried out by local government mosquito control agencies. These were described as shallow and broad spoon-shaped “tidal circulation channels” (Easton 1986) and were the model for runneling introduced in Qld in 1985 (Hulsman et al. 1989). Today in NSW, permits are required for works on Crown lands from the Department of Industry–Lands and, in intertidal areas, from the Department of Primary Industries (Fisheries). In the NT, assessment is required only for source reduction on previously undisturbed land.

Enabling legislation: In Australia, mosquito control is a state/territory and local government responsibility, and so the enabling legislation varies between states/territories. In Qld, under the State Public Health Act 2005, mosquitoes are a “designated pest” (Schedule 2) and must be controlled, with responsibility delegated to local government under the associated regulations. While it is mandatory for local governments to administer and enforce the mosquito control provisions, not all have the resources to do so, as mosquito control is often combined with several other health-related activities, such as restaurant inspections, or vermin and weed control. In view of the general environmental duty under Section 319 of the Qld Environmental Protection Act (QEPA) 1994, there is a risk of prosecution should harm occur as a result of mosquito control actions. However, the Local Government Association of Queensland Mosquito Management Code of Practice 2014, if followed, removes liability under the QEPA 1994 for any harm that may be caused. Runneling is the only source reduction work carried out in Qld. Under the new Planning Act 2016, runneling is considered “accepted development” S43 (1), and permits are not required.

In NSW, a permit or license must be obtained for any source reduction in the intertidal wetlands under the NSW Environmental Planning and Assessment Act 1979, with Fisheries as an “approval body.” Mosquito habitat wetlands are protected under State Environmental Protection policies, and this may generate conflict for control. However, in practice, the often already-disturbed nature of the wetlands and the potential for modification to restore tidal processes facilitate permitting, and so far, no efforts have been refused. A more integrated approach towards managing intertidal systems for services such as fisheries and wildlife and carbon sequestration values is currently being developed. It is important that this approach incorporates the need to manage the mosquito hazard.

In the NT, the Public and Environmental Health Act 2011 and its Regulations 2014 (Part 4 Mosquito Control) delegate responsibility for mosquito mitigation to the landowner or occupier.

Cooperation/coordination among authorities: Queensland was the first state to have a formally constituted cooperative local government group for mosquito control. Known as the Contiguous Local Authorities Group (CLAG) and established in the early 1980s, it was created in response to recognition that mosquito management needed to be integrated across administrative boundaries through agency collaborations. The first CLAG covered an area south of Brisbane to the Gold Coast and was joined by Tweed Shire Council (NSW). It is currently called the Regional Mosquito Management Group (RMMG). Later, CLAGs were created so that the whole of southeast Qld was covered.

In addition to CLAG, the Local Authorities Research Committee (LARC) was established in 1992 to “stimulate and evaluate research carried out with respect to saltmarsh mosquito control, and secondly to act as a coordinating body to foster operational development” (LARC 1999). The committee included voting member participants from both state and local government as well as researchers as advisors. In 2001, LARC became the Mosquito and Arbovirus Research Committee (MARC).

Within NSW, a place-based coastal and estuary management program has been developed over 20 years based on local authorities developing plans, consistent with a statewide framework, that prioritize actions agreed among government agencies and the local community. However, this program is not specifically for mosquito issues. It is notable that the northern Tweed Shire Council collaborates in the Qld RMMG. In addition, there have been short-term collaborative projects by adjoining local governments in NSW (e.g., the Newcastle, Sydney, and far north coast regions), which are typically overseen by the state health authority. However, these regional approaches did not specifically include mosquito control activities, and mosquito risk was primarily addressed through community education.

In the NT, the Mosquito Control Measures Committee, consisting of members from the Darwin Council, the Department of the NT, and the NT administration, was established in 1963 primarily to follow up on public mosquito complaints. In 1983, the combined Mosquito Engineering Program between the Darwin City Council and NT government commenced to mitigate larval mosquito habitats and upgrade and maintain existing stormwater drains in Darwin (Whelan 2007). Since the establishment of the NT Disease Control Program in 1988, the Department of Health, local councils, and the Conservation Commission have maintained a close collaboration for mosquito control. In 1990, the Mosquito Control Advisory Committee was created and included members of the Medical Entomology unit of the Department of Health, the Communicable Disease Branch, medical practitioners, the Legislative Assembly, Darwin City Council, the Conservation Commission, and defense and community members. Its role was to review existing programs...
and assist with decision making. Other collaborations exist between the Department of Health Environmental Health unit and local councils.

**OWNERSHIP AND MITIGATION FOR SOURCE REDUCTION PROJECTS**

This section addresses the issue of ownership and mitigation involving source reduction projects. As in the previous section, it concentrates on intertidal wetlands.

**Florida**

*Private versus governmental ownership of wetlands:* Mosquito control programs regularly operate on private property, including larval inspections and control, adult mosquito surveillance, or informing property owners of the mosquito problems they might be creating. Adulticide applications are usually designed to drift onto property, which regularly includes privately owned land. For mosquito control programs responsible for managing impoundments, the need to access and manage privately owned properties is even more complicated by the impoundments, which need regular management and maintenance.

Since the early 1980s, mosquito control programs along the IRL have been managing impoundments for both mosquito control and natural resource values via rotational impoundment management. This involves installing culvert pipes through earthen impoundment dikes to provide a seasonal reconnection of the impounded marsh with the adjacent lagoon. Culverts are closed in the spring, and impoundments are flooded with lagoon water to deny salt marsh mosquitoes oviposition during the summer and early fall, when they are reopened to allow for the exchange of water and organisms until the next spring when the culverts are again closed. Rotational impoundment management allows for the reestablishment of many of the marshes’ natural functions while virtually eliminating the need for larvicide applications in these impounded areas (Carlson et al. 1991).

Around 1970, some property owners incorrectly concluded that impoundments created on their property made them wetlands, with several requesting that no water should be pumped into their impoundment or that dikes should be breached to prevent planned flooding during the summer months. At the Indian River Mosquito Control District (IRMCD), the board of commissioners agreed to the requests to not flood but continued to inspect and larvicide as needed. This made for a more expensive and frequently less effective control method in these locations. It could be argued that the district could have denied requests and continued to flood during the summer months, as both the Florida statutes and enabling legislation for individual mosquito control districts have denied requests and continued to flood during those months. It could be argued that the district could have denied requests and continued to flood during the summer months, as both the Florida statutes and enabling legislation for individual mosquito control programs are quite powerful in their authorizations.

Consequently, the situation went from wetlands being considered wastelands to areas of extreme environmental significance that are protected by the federal U.S. Army Corps of Engineers, and state (Florida Department of Environmental Protection, water management districts) and local (city and county) authorities. Research findings changed opinions concerning wetlands, and mosquito control offices had to adapt while still carrying out their mandates.

*Mitigation:* In the 1980s, some impoundments became the targets of developers as it became apparent that they could be used as mitigation to allow the developer to gain some additional waterfront properties. Developers often funded improvements to impoundments in the form of culverts and pumps and in turn gained some additional developable land. These water-control structures are usually turned over to the mosquito control office to manage into the future in accord with a management agreement acceptable to all parties.

*Mitigation banks:* Since the 1990s, mitigation banking has played a role in shaping some salt marsh management projects and is a concept by which a developer, governmental body, or individual can make what are considered environmental improvements to their property now, be awarded credits for those improvements, and then sell those credits, either now or in the future. This sale can be to any entity needing to mitigate for environmental impacts. The concept was developed because since the 1970s, individual mitigation work had been primarily small, noncontiguous projects that did not provide broader ecosystem benefits. Additionally, in many cases, the regulatory agencies realized that these projects were not successful in achieving their environmental objectives. When properly implemented, mitigation banks have the potential to minimize mitigation uncertainty and provide ecological benefits that were not being met by traditional mitigation. Only after the project has been deemed a success will all the credits be awarded to the initiator of the mitigation bank project (Carlson et al. 1999). In Florida, freshwater mitigation banks have been much more prevalent than salt marsh banks. However, it is the salt marsh banks that have the greater potential to impact development in estuarine environments.

**Australia**

*Private versus governmental ownership of wetlands:* In Australia, the mean high-water mark is an important administrative and legal boundary that usually distinguishes Crown and other publicly owned seaward lands from upslope lands, which are mainly privately owned. Tidal wetlands and their fringing mosquito habitats span these jurisdictions. In populated areas, numerous private landholders may own parts of a tidal wetland, and there may also be multiple agencies with issue-specific management roles (Dale et al. 2010). Effective mosquito and
Mitigation and offsets: In Australia, there has been a recent move to conduct “offsetting.” This is a process with some similarities to mitigation banking, whereby a developer who wishes to “develop” a sensitive area can contribute funds or do operational work to recompense the “loss.” The Queensland Environmental Offsets Act 2014 coordinates offsets for the whole of Qld, where it is legislated at the state level but is implemented locally. It is supported by the Environmental Offsets Regulation 2014 and the Queensland Environmental Offsets Policy 2017. The main purpose of the offset legislation is “...to counterbalance the significant residual impacts of particular activities on prescribed environmental matters through the use of environmental offsets” (Environmental Offsets Act 2014, Part 2, Section 3[1]).

In NSW, the state-level Biodiversity Conservation Act 2016 and the Fisheries Management Act 1994 established frameworks to avoid, minimize, and offset impacts of development on terrestrial and aquatic habitats respectively. For aquatic habitats, the specific provision of the act states that: “A permit may include conditions requiring the permit holder to enter into a bond or guarantee or other financial arrangement for the due performance of the holder’s obligations under this Act” (§220).

The Fisheries Agency Policy and Guidelines require that habitat compensation for aquatic habitats should be undertaken in the vicinity of the impacted site, for the same type of habitat that has been lost, and at a minimum 2:1 basis. This minimum rate applies for all key fish habitat areas, recognizing both indirect impacts and the time needed for the compensatory area to deliver a similar range of environmental services. A subset of coastal wetlands is also protected under planning legislation, and the fisheries authority requires that impacts to these coastal wetlands is to be offset at a rate of 10:1. An additional tool used in NSW involves a requirement for a proponent to provide funds as an environmental bond that may be returned upon satisfactory completion of the works in accordance with all permit conditions, which could include monitoring requirements. Offsetting is required in degraded as well as high-quality wetlands to avoid creating a perverse incentive for wetland values to be degraded prior to the environmental assessment for the proposal.

There is no offset system in NT, but there is close liaison among the Department of Health, the Department of Infrastructure Planning and Logistics, and developers during the development phase.

LAND-USE PLANNING AND MOSQUITO CONTROL—A MISSING LINK?

Florida

County mosquito control programs typically are part of the review process for new developments, and thus they are usually able to ensure that mosquito control considerations are taken into account in the development review process. That can be more difficult for independent mosquito control districts, which are a separate governmental entity and are not part of county government. However, in some locations, such as with the IRMCD, the county development review process solicits and welcomes input from mosquito control districts, making certain that the developer addresses the concerns of the independent mosquito control program. Mosquito control districts then use this opportunity to receive a formalized easement to allow for guaranteed access for inspection and control activities. However, even these steps do not prevent the increasing prevalent situation of residents adjacent to larval treatment areas complaining about the low-flying plane passing so near to them.

Australia

Land-use planning in Australia is managed within each state by local governments, or at a higher level in NT. In Qld, there is no provision in the Planning Act 2016 for mosquito control to have any input into the assessment of development applications. Usually, there is no communication between development planning and mosquito management, which can result in planning outcomes with significant issues both for human health and mosquito control. For example, a recent development proposal did not consider mosquito management, and the design directed stormwater discharges into a wetland, resulting in an increase in mosquito habitat, an extended mosquito season, and increased mosquito control costs that were not financed by the developer.

In NSW, development on public lands is regulated by the Crown Land Management Act 2016, while issue-specific legislation such as the Fisheries Management Act 1994 and the Water Management Act 2000 have some provisions that span public and private tenures to manage activities associated with development. Conditions for approvals under these acts are usually determined at the development assessment stage. The challenge of overlapping jurisdictions, particularly in the intertidal coastal wetlands, has been widely recognized, and an object of the Marine Estate Management Act 2014 is: “to promote the co-ordination of the exercise, by public
authorities, of functions in relation to the marine estate.” For land-use planning, the Environmental Planning and Assessment Act 1979 provides a regulatory framework for specific state-based planning issue instruments, and, at the local level, a strategic planning statement is required to guide development. Local councils must consider planning instruments when determining a development application.

A recently adopted, issue-specific state planning instrument, the Coastal State Environmental Planning Policy 2018, updates the State Environmental Planning Policy 14 (Coastal Wetlands) and accompanying site-specific maps initially published in 1984. Among other matters, the new coastal management programs address “risk associated with coastal hazard and threats to healthy coastal ecosystems,” which may encompass mosquito management, particularly where habitat modification–based responses also improve wetland function.

Development Control Plans (DCPs) are available to NSW local government authorities. Their purpose is to provide local guidance on the matters that should be considered during the planning assessment of a particular site or with regard to a specific issue. The DCPs are not enforceable, and, if challenged in court, the influence of these documents will depend on a local authority demonstrating a consistency in application and operation of the DCPs. The DCPs guiding planning in mosquito hazard areas have been published by three local authorities within northern NSW. The mosquito-related DCPs recommend providing general advice to residents and prospective developers; identifying risk zones; and requiring the consultancy team to include an entomologist. They acknowledge that on-site habitat modification may reduce biting insect production. However, the opportunity to link rehabilitation of wetland function and delivery of other ecosystem services with mosquito source control is not recognized.

A remaining issue not adequately covered by the NSW planning system (and possibly a problem in other jurisdictions) occurs when preexisting infrastructure modifying the landscape can result in an emerging mosquito problem as settlement encroaches towards it. The example is where a ridge was constructed across an intertidal inlet in the early 1960s to house a power cable. It created an impounding effect in the upper area, creating a mosquito habitat. By 2015, when the surrounding area had been converted to residential development, the mosquito hazard became a problem. A solution was to breach the obstruction, and, fortunately, the presence of the power cable was noted prior to work. However, when infrastructure from a previous land use is repurposed and incorporated into the design of a new development, the opportunity to modify and better manage mosquito hazard or improve wetland function can be constrained or eliminated.

Likewise, the activities of community groups to rehabilitate damaged habitats, including intertidal wetlands, need to be carefully managed to maximize opportunities to reduce mosquito hazard rather than create mosquito habitats and exacerbate the problem. In a survey of 108 projects in NSW and Qld, Knight (2018) found that only three projects referred to mosquito issues.

The early days in NT are best exemplified by reflections of Peter Whelan, who controlled mosquitoes for many years. He has written (with minor editing):

> From the start of my time in Northern Territory health in 1974, I recognised urban planning and proper engineering construction was [were] the most important aspect[s] of preventing mosquito-to-borne disease. Perhaps the first breakthrough was the recognition by the Northern Territory government of the 1.6-km or 1-mile limit of urban development from large and uncontrolled significant mosquito breeding sites.

> The next step was to be involved in the planning process, and I had success to ensure that Medical Entomology aspect and human health were high in importance in environmental impact statements, and all development included examination of potential impact of biting insects.

The NT differs from other jurisdictions in Australia with regard to urban subdivisions, with planning at a higher level of governance. The territory government has been strongly involved in urban planning since the 1970s (Whelan 1989) and drives the process through the Department of Infrastructure Planning and Logistics with direct input from the Department of Health (Medical Entomology). This strong NT government involvement assists the Department of Health in advancing the mosquito and biting midge agenda, primarily with regard to urban residential buffers from major mosquito and biting midge production areas, and source reduction by drain design and drain end-point discharge. In some cases, buffers can be relaxed by block size and use following discussions with the Department of Infrastructure Planning and Logistics.

As an example of strong links between planning and mosquito issues, the design of the satellite city of Palmerston is one of the few large urban developments with buffers, drains, and wetland considerations to eliminate mosquito problems by good urban planning (Whelan 1989). More recently, a development has been approved with a 50-m open buffer so that the NT mosquito control does not have to deal with the brackish water mosquito *Verrallina funereal* (Theobald). For that species, a 50-m buffer would be important and highlights the need to understand the mosquito problem at the species-behavior level in order to manage effectively.

The NT Department of Health has advisory input to the final asset owner regarding stormwater...
infrastructure design. However, issues still occur on the downstream side of subdivisions, due to the complexities of building drains beyond the development boundary. These issues include who pays for and maintains a mosquito prevention drain required for residents of the new development if it lies outside the council boundary and outside the area of responsibility of a developer. The same applies to mosquito control, with potential mosquito production sites usually excised from new subdivisions and handed back to the NT government, but with no subsequent increase in mosquito control funds to protect the new residents.

**DISCUSSION AND CONCLUSION**

Some similarities and differences among Florida and the three areas in Australia are shown in Table 1, and they illustrate various strengths and weaknesses. A common strength of mosquito control is its long history of improvement, adoption of cost-effective control methods, and environmental awareness. In all areas, the mosquitoes, their larval habitats, and the methods used to manage them have some commonalities, though the actual methods of control may differ to some extent. Although all the areas manage mosquito larval habitats, the main difference in treatment is that local agencies in Qld and NSW focus on aerial or ground spraying with larvicides, with relatively little environmental modification. In contrast, Florida and NT have significant and successful engineering approaches to managing larval habitats. The source reduction programs are strengths because they achieve long-term cost-effective control regardless of tidal or weather changes. In contrast, larvicidal applications need to be repeated, and environmental changes may make this method vulnerable to increasing costs if more frequent treatments are needed, as has occurred in Qld (Dale et al. 2018).

A major issue in Qld, NSW, and Florida is that population continues to increase. However, in Qld and NSW, there is little or no connection between mosquito control and urban planning at the local government level. Consequently, reliance on larviciding makes the agency more vulnerable to both urban encroachment and environmental change, which is a significant weakness. In contrast, in east-central Florida and the NT, with integration at a higher level of governance and a much greater use of source reduction, the problem is more effectively managed. For Florida, this may reflect the much longer timescale and hence more mature mosquito management than in Qld and NSW, where mosquito control can be considered relatively young. For NT, this may also reflect a longer timescale than for Qld and NSW, but also the higher level of governance and the early influence of defense considerations. The lesson may be that local level government is not yet ready, or able, to integrate across its various levels of responsibility, and this may be related to a lack of organizational connectivity or available resources. Addressing those weaknesses is an opportunity for more effective liaison between planning both for land use and mosquito management.

An important goal is to have effective communication between mosquito control agencies and development planning, as occurs in Florida and NT. This will help prevent, or at least minimize, the situation of a development project being approved and then learning that the local mosquito control agency’s ability to carry out the necessary work is jeopardized. This threatens the adequacy of mosquito control, which is an important amenity for nearby residents. Such communication is especially important because increasing numbers of development projects are being proposed and constructed adjacent to estuarine mosquito-producing habitats. To avoid conflict, mosquito control agencies and land-use planners need to collaborate. It is heartening that this is an emerging area of opportunity that will benefit both land users and mosquito control operations, and thus the public. Also of importance over the past decade, Florida has experienced cases of locally transmitted pathogens (e.g., dengue, chikungunya, Zika) associated with container mosquitoes (e.g., *Aedes aegypti* (L.), *Ae. albopictus* (Skuse)). It is important that a shift of resources to address this problem, at the expense of salt marsh mosquito control efforts, does not become the norm. Both are important components of a comprehensive coastal mosquito control program and deserve proper attention.

In conclusion, there is little question that over the past 60+ years, mosquito control and coastal development have greatly influenced each other, whereby advances in mosquito control have resulted from demand related to urban expansion (mainly in Australia), and urban expansion has been facilitated by advances in mosquito control (mainly in Florida). The comparison described in this article has highlighted similarities and differences between mosquito management issues in east-central Florida and the subtropical states and a territory in Australia. The major strength in all areas is the relatively long time frame over which control programs have developed using a strong science-based approach. These programs are now well tested and have resulted in effective mosquito control in all areas reviewed. Although the time frame is shorter for local government agencies in Qld and NSW, all have benefited by learning from the work that has been done in Florida and other parts of the USA. This article demonstrates that in the areas we examined, an identified difference is the way in which urban development is handled related to level of governance. In east-central Florida counties and Australia's NT, development planning and regulation are quite well integrated with mosquito control needs. In contrast, at Australia’s local government level within NSW and Qld, integration between planning and mosquito control is not consistent, which frequently
### Table 1. Comparing east-central Florida and Australia (Queensland [Qld], New South Wales [NSW], Northern Territory [NT]) relating to mosquito control, land-use planning, and development near estuarine areas.

| Topic                                      | East-central Florida                                      | Qld, NSW, and NT                                      |
|--------------------------------------------|-----------------------------------------------------------|-----------------------------------------------------|
| **Similarities**                           |                                                            |                                                     |
| Population                                 | 21 million with coastal preferences                      | 14 million with coastal preferences                  |
| Management authority                       | Local agencies with state oversight                       | Territory and local government                       |
| Mosquito habitats                          | Mangrove swamps and salt marsh                           | Mangrove swamps and salt marsh                       |
| Mosquito nuisance and disease              | Concern is primarily salt marsh mosquitoes as nuisance in | Nuisance and disease vector mosquitoes               |
| transmission                                | estuarine areas                                           | Ross River and Barmah Forest viruses transmitted by saltwater and freshwater mosquitoes, dengue present (peri-urban) |
| Temporary mosquito control                 | Ground and aerial larvicidings are common                 | Qld: aerial larviciding common                       |
|                                           | Truck ultralow-volume spraying common with some aerial    | NT: well-established aerial larviciding program in Darwin area, which is impractical in coastal swamplands, and so most other communities are unprotected |
|                                           |   adulticiding                                             |                                                     |
| Environmental modification                  | Extensive management of impoundments using the technique of rotational impoundment management (RIM) | Qld: some runneling                                 |
| (=source reduction)                        |                                                           | NSW: some modification in mangroves                 |
|                                           |                                                           | NT: only well-established mosquito engineering program in Australia |
| **Differences**                            |                                                            |                                                     |
| Reason mosquito control was implemented    | Desire of citizens                                        | To improve settlement amenity, facilitate military operations, and minimize mosquitoborne disease threat |
| Funding source/extent                      | East-central Florida programs adequately funded by property taxes | Funding limited, mostly from local rates (=property taxes) |
| Land ownership: private vs. public and tenure | Estuarine areas owned largely by government (federal, state, local), some private, not-for-profit organizations | Qld: mosquito agencies do not own land but carry out control on public and private lands |
|                                           |                                                           | NSW: land is council and privately owned, where mosquito control is done with landowners’ support in compliance with regulators’ requirements |
|                                           |                                                           | NT: owned by the Crown (held in leases) or by defense entities (Commonwealth) |
| Land issues                                | Coordinating with landowners concerning the control actions that can be implemented on their property | Qld: issue of local government funding mosquito control on state land |
|                                           |                                                           | Qld: local government can arrange/ undertake mosquito control on private lands |
| Development planning/ mosquito management interests | Interagency inputs to development planning typically include cooperation with mosquito control interests | Qld:- urban planning and mosquito control generally lack integration |
|                                           |                                                           | NSW: Development Control Plans (DCP) are a step forward but only provide guidance (=no statutory enforcement) |
|                                           |                                                           | NT: government /Department of Health program, government sign-off necessary (=unique arrangement) |
| Mitigation/offsets for development impacts | Developers frequently allowed to mitigate for wetland impacts by improving wetlands Mitigation banks established with goal to make process more efficient and effective | Qld:- offsets are a recent phenomenon and are undertaken opportunistically |
|                                           |                                                           | NSW: efforts underway to implement offsets in a more coordinated, strategic manner |
|                                           |                                                           | NT: no offset policy                                 |
results in development encroaching into troublesome mosquito habitats without mosquito control being adequately considered, thus hindering the ability of mosquito control agencies to respond. However, this is a weakness that can be corrected. Nevertheless, where collaboration exists between mosquito control and planning agencies, we have seen the strong ability to minimize conflicts, resolve problems, and make for improved residential conditions, especially as it relates to mosquito annoyance and public health considerations.

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