Chapter 33
Planning Development to Reduce Mosquito Hazard in Coastal Peri-Urban Areas: Case Studies in NSW, Australia

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Abstract In this chapter we take a multidisciplinary approach to evaluating planning for coastal development, particularly in peri-urban areas. We consider ecosystem services and disservices and how, in the past, much development was at the expense of coastal wetlands. We then focus on mosquito production as a wetland related disservice that affects residents and imposes costs on individuals and government from both a health and management perspective. Most coastal peri-urban areas including adjacent wetland sites retain legacy infrastructures and landforms that degrade wetland function and often exacerbate the mosquito hazard. Rehabilitating coastal wetlands can improve wetland function while also reducing the mosquito hazard. Yet examination of rehabilitation and mosquito management within the existing planning framework found deficiencies and complexity. In particular, coastal wetlands are almost always overlaid with a number of different zone and ownership boundaries that increase complexity of both mosquito management and wetland rehabilitation actions. We illustrate the issues with two case studies from northern New South Wales (NSW), Australia: a greenfield development located in Ballina and a retrofitted site at Banora Point near Tweed Heads. We recommend land use planning frameworks incorporate a trigger for both assessment of adjacent coastal wetland ecosystem function and restoration of wetland ecological processes that includes provision for habitat based source control of mosquito hazard and coastal wetland rehabilitation.

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33.1 Introduction

Population growth in Australia is concentrated in the coastal zone, and especially along the south east of the continent (ABS 2014) where enjoyment of the coastal environment is a strong attraction for many people. Growth pressure has produced increasingly rapid coastal zone development and has been termed the 'sea change' phenomenon (Gurran et al. 2006). However, the geography of the coastal zone, including rivers, wetlands and floodplains, is a constraint on urban development that has led to peri-urban development close to the coast. Coastal peri-urban areas are a temporal and spatial mosaic of agricultural land and open spaces being gradually converted to housing with some natural areas being retained for green space.

In this chapter we take a multidisciplinary approach to examining planning issues for coastal development in peri-urban areas. Initially we look at coastal wetlands, and the incumbent mosquito hazard, in the context of ecosystem service. The issue of mosquito production receives little consideration in planning even though mosquito borne diseases and mosquito control incur considerable cost for individuals and government. We also consider the legacy of past impacts on coastal wetlands and issues around rehabilitation that are rarely incorporated into planning, though the impacted wetland can be a constraint for development and future residents. Through two case studies, a 'greenfield' and a 'retrofit' development, we explore some options to address these impacts on coastal wetlands.

Greenfield developments often involve the subdivision of agricultural or open space land and the provision of urban infrastructure such as roads, green space and other services. Retrofit developments occur at already developed sites and involve modifying infrastructure to minimise unintended environmental impact, for example, incorporating water sensitive urban design features into an existing stormwater network. Replacement, technological improvement or additional information can be retrofit triggers. Retrofit works are often costly, involving design and outcome compromises because of constraints imposed by the existing infrastructure setting. Consequently, there is little commercial incentive to undertake retrofit works which are therefore generally undertaken by public authorities often in response to regulatory risk. By contrast greenfield developments are generally undertaken for commercial profit. Both development types can require approvals from relevant authorities.

33.2 Ecosystem Services: A Context for Development

The ecosystem services concept provides a common language for ecologists, planners, resource users, decision makers and the broader community to contribute and evaluate technical and experiential information about the links between human and ecological systems (Granek et al. 2010). Ecosystem services are the 'products of nature that directly benefit humans' (Schmidt et al. 2014, p. 57) and where these products have a negative impact or cost there can be an ecosystem disservice (Lyytimaki and Sipila 2009). Coastal wetland services include fish and bird habitat and coastline protection and have economic value, while disservices, such as mosquito production, can have social, economic and health costs (Dale and Knight 2012). Without effective safeguards peri-urban development in coastal environments can reduce delivery of ecosystem services and increase delivery of ecosystem disservices (Niemelä et al. 2010).

33.2.1 Coastal Wetlands in Peri-Urban Areas

Intertidal coastal wetlands are dynamic systems that are habitat for mangrove and saltmarsh plant communities. They deliver a wide range of ecosystem services (Perillo et al. 2009) providing a range of value and non-value uses (see Barbier et al. 2010 for a detailed review) including nursery habitat for commercially and recreationally important fish species (Sheaves et al. 2014), habitat for migratory birds (Visser and Baltz 2009) and aesthetic green spaces. Coastal wetlands improve water quality by stripping nutrients and intercepting sediments, and they reduce erosion by protecting the foreshore from waves and currents (Costanza et al. 2006). In addition, mangrove and saltmarsh are amongst the most efficient ecosystems in the world at sequestering carbon (Saintilan et al. 2013) and are being investigated for future Blue Carbon opportunities (e.g., Mcleod et al. 2011; Irving et al. 2011).

However loss of coastal wetlands is a major concern globally (Irving et al. 2011) with urbanisation and development identified as the most common cause of mangrove loss (Dale et al. 2014). Losses in New South Wales (NSW) Australia have been estimated at 60 % for the period from European settlement (1788) to 1970 (Goodrick 1970) with losses continuing to occur (Pressey and Middleton 1982). More recently loss of saltmarsh (Saintilan et al. 2014) has resulted in its listing as an endangered ecological community within NSW and nationally.

The high conservation value of coastal wetlands is now better recognised with many protected by legislation and sometimes via land use zonings. However, even when there is protection via zoning or other means, coastal wetlands often retain legacies of past land uses that pre-date the zoning. Clearing, draining and construction of roads associated with agricultural and urban development are major contributors to loss, fragmentation and degradation of coastal wetlands (Williams and Watford 1997). In the NSW coastal zone several thousand structures that could

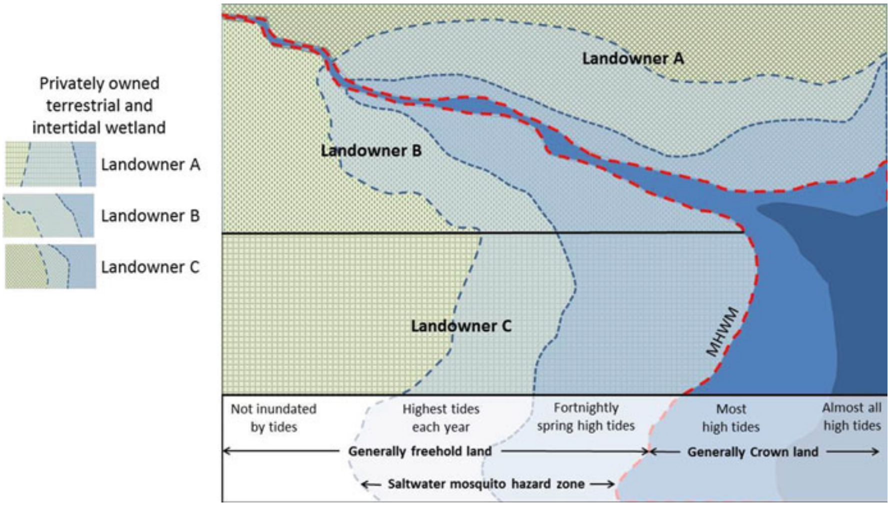

Fig. 33.1 Coastal wetlands and jurisdictional boundaries in NSW

affect wetland hydrology leading to wetland damage and loss were identified by Williams and Watford (1997). Structures identified included field drains, floodgates, culverts and levees that were originally installed to alter tidal hydrology and improve agricultural potential. However in a post agricultural peri-urban landscape, such infrastructure is often redundant or orphaned due to the land use change. Yet, even in a deteriorated state, they often continue to operate suppressing tidal processes, fracturing ecological function and impacting on wetland ecosystem service delivery. Underpinning these changes is alteration of two key ecosystem functions: hydrology and sedimentation (Lee et al. 2006). Disservices that can result include poor water quality resulting from exposure of acid sulfate soils leading to fish kills and reduced oyster aquaculture production, loss of coastal wetland vegetation and weed incursion, unpleasant odour from rotting vegetation and increased mosquito hazard (Knight et al. 2012). Also soil compaction and subsidence resulting from long term desiccation can occur due to altered tidal function (Rogers et al. 2006).

Land tenure and jurisdictional boundaries influence the response to ecosystem disservice. In NSW the Mean High Water Mark (MHWM), a statistically derived conceptual line, is used as both a natural feature boundary and a zoning and property boundary. Consequently, coastal wetlands, which almost always extend landward beyond the MHWM, are often intersected by arbitrary boundaries (Fig. 33.1). Generally, Crown land (public land owned by the State) occurs below the MHWM. Freehold land generally extends landward from the MHWM across tidal and supratidal wetland areas (inundated by only the highest tides of the year) into terrestrial environments. Tidal and supratidal areas above the MHWM, are however, both an integral component of the coastal wetland environment and the areas with the greatest risk for saltwater mosquito production (Knight 2011). Furthermore, multiple private owners are often co-located within a single coastal wetland and this can increase the complexity of saltwater mosquito management and more broadly, coastal planning.

33.2.2 Mosquito Hazard: An Ecosystem Disservice

Saltwater mosquitoes, *Aedes vigilax* and *Ae. camptorhynchus*, breed prolifically in mangrove and saltmarsh areas where their lifecycle is tuned to tidal cycle inundations such as fortnightly spring tides (Knight 2011). Apart from a blood meal, the main prerequisites for saltwater mosquito breeding success are: moist substrate on which eggs are laid, flooding to trigger egg hatch, and, standing water to provide a habitat for larval development. The whole process can take as few as 11 days in summer. But when conditions are unsuitable saltwater mosquito eggs can survive both desiccation and multiple wetting-drying cycles before hatching. Consequently, a store of viable eggs can build up ready to hatch when conditions are suitable (Knight 2011).

Apart from breeding in natural habitats, large populations of saltwater mosquitoes are often a symptom of degraded coastal wetlands (Webb and Russell 2009; Webb 2013). Tidal inundation, water quality and mosquito production are influenced by a site's microtopography. Differences in relative elevation of the ground surface within the wetland as little as 0.1 m may be sufficient to facilitate mosquito production (Knight et al. 2009, 2013a; Griffin et al. 2010). Consequently, even small depressions, vehicle tracks and mounds of sediment incidentally left in tidal areas from development or agricultural activity can unwittingly increase the saltwater mosquito hazard. Also, disturbed wetlands, artificial drains and artificial drainage areas have been found to produce some of the highest densities of saltwater mosquito larvae (Gislason and Russell 1997; Jacups et al. 2009).

Saltwater mosquitoes are a significant health hazard because they are vectors for the two main mosquito borne viruses affecting people in coastal Australia: Ross River virus (RRv), and Barmah Forest virus (BFv) (Naish et al. 2006; Russell 2002). These diseases bear significant cost for both society and the individuals affected (Harley et al. 2001; Ratnayake 2006). RRv is the most common and important (Lyth et al. 2005) with close to 5000 cases reported each year in Australia (NNDSS 2014). It causes polyarthritis with debilitating arthritic symptoms that may persist for several months incapacitating some adults for 5–6 weeks. For some people recovery may take longer and chronic fatigue type syndrome persists in ~10 % of patients (Gilbert et al. 2013). BFv has similar symptoms to RRv but is less prevalent with an average of 1868 notification annually (NNDSS 2014). Mosquito control is also costly. Data for Queensland show that costs, for the State, rose from AUD7 million in 1993 to AUD11 million in 2004 (Tomerini 2007) and may have exceeded AUD20 million in 2014.

Kangaroos and wallabies are a major natural reservoir of RRv, causing the disease to be thought of as a rural one, but it is increasingly prevalent in peri-urban environments (Webb 2014; Tong et al. 2008). In addition, saltwater mosquitoes can disperse widely in their search to find a blood meal and, with wind assistance, can range up to 50 km from larval habitats in coastal wetlands (Naish et al. 2012). This has consequences for the 80 % of Australians who live within 50 km of the coast (ABS 2014).

33.2.3 Managing Mosquitoes

Integrated mosquito control programs (IMCPs) use a variety of chemical products and methods to control mosquitoes while minimising cost and resistance issues. Currently IMCPs focus on treatment of larval habitats using chemical larvicides (such as *Bacillus thuringiensis* var *israelensis*) or insect growth regulators (such as S-methoprene). Generally, chemical control is achieved by aerial application but in areas with dense vegetation (e.g., sedge *Juncus* sp.) the canopy can reduce the amount of larvicide reaching the pools where the larvae reside (McGinn and Sullivan 2013). Mangrove canopy is likely to cause a similar limitation. Pelletised and briquette formulations of chemicals can overcome the problem of dense canopies but often require more time consuming direct application. In NSW mosquito control is not mandatory and only a limited amount of aerial spraying occurs, mainly in the Tweed local government area just south of the Queensland border.

Another method used in IMCPs is source reduction. This involves modifying the environment to minimise conditions suitable for mosquitoes. In Australia this is usually achieved by runnelling, a process that involves construction and maintenance of shallow channels that connect saltmarsh pools to the tide source to modify the tidal inundation regime to one less suited to saltwater mosquitoes (Hulsman et al. 1989; Dale and Knight 2012). LiDAR data has been used to detail the microtopography within mangrove systems enabling runnel-like techniques to be tested in mangrove environments (Knight et al. 2009).

33.2.4 Development Buffers: An Indirect Approach

Planning decisions can complement IMCPs by providing for buffers between mosquito habitats and urban settlement. The buffers are cleared areas between housing developments and known mosquito habitats. They can reduce the hazard from some mosquito species (such as *Verrallina funerea*) that disperse only relatively short distances (<1 km). Maintenance is needed to prevent establishment of understorey or continuous vegetation that provide harbourage or flight corridors. Mosquito buffers can also serve as bushfire asset protection zones and contribute to open space within a development. When bounded by a single fronted road defining the urban edge, they also assist in delineation of public and private space.

33.2.5 Rehabilitation

To mitigate adverse effects of past development rehabilitation has the potential to restore some coastal wetland function and minimise mosquito issues. Rehabilitation has been defined by Elliott et al. (2007, p. 354) as 'the act of partially or, more rarely, fully replacing structural or functional characteristics of an ecosystem that have been reduced or lost…'. Elliott et al. (2007) goes on to note that: '…the rehabilitated state is not expected to be the same as the original state or as healthy, but an improvement on the degraded state.' The intent is to provide more ecosystem services and fewer disservices, (i.e., positive not negative outcomes).

Identifying and rehabilitating the ecological functions that drive ecosystem service provision should be a focus of rehabilitation efforts (Simenstad et al. 2006). Key to rehabilitation success is a thorough understanding of the issues and options followed by restoration of the appropriate hydrologic conditions (Lewis 2005; Turner and Lewis 1996; Dale et al. 2014). In practice, this can become complicated where unintended/unforeseen outcomes can occur. For instance, Turner and Streever (1999) increased tidal flows in a coastal wetland by removing two small culverts in a road crossing, replacing them with a channel and bridge. They found that reconnecting tidal flushing significantly reduced mosquito production in the immediate vicinity. However, increased tidal connectivity into the rehabilitated marsh also enhanced flushing to the high marsh areas and, in one area, this actually enabled mosquito production. Webb (2015) recommends judicious use of chemical larvicides to limit the potential for mosquito hazard during the initial response phases of wetland rehabilitation as ecological functions re-establish.

Many coastal greenfield development sites within NSW occur in a peri-urban landscape with agricultural or post agricultural features. Well planned greenfield developments, in addition to minimising impacts can undertake actions to rehabilitate the adverse effects of previous land uses. Such rehabilitation has the potential to not only restore some wetland function, but also to minimise mosquito issues.

33.3 Planning Framework for Coastal Development in NSW

Within the state of NSW there are policies for wetland management. These include three state-wide policies that support protection and rehabilitation of wetlands: NSW Wetlands Policy (NSW Govt 2010), NSW Fish Habitat Conservation and Management Policy and Guidelines (NSW Govt 2013), and NSW Biodiversity Offsets Policy (NSW Govt 2014). The three policies are intended to work together to outline where development impacts on wetlands should be avoided, mitigated or offset with rehabilitation works at another site. In addition to consideration of these policies, some development proposals may trigger approval requirements under other NSW legislation such as the *Water Management Act* 2000 or the *Fisheries Management Act* 1994. Conditions for approvals under these Acts are generally determined at the development assessment stage via referral to relevant state agencies.

Within NSW there is also a state based planning and zoning regulation framework that establish how land can be used and how that use can be changed. The principal planning statute in NSW is the *Environmental Planning and Assessment Act* 1979. State Environment Planning Policy 14 Coastal Wetlands (SEPP14), gazetted in 1984, is a planning instrument that influences management of mosquito hazard. It prescribes that within mapped SEPP 14 wetlands clearing of vegetation, levee bank construction, draining and filling activities require assessment by an environmental impact statement. Consent authorities such as local councils must apply state planning instruments when determining a development application. They also consider Local Environmental Plans (LEPs) which are legislative documents that outline permissible land uses within mapped zones. Development Control Plans (DCPs) are non-legal, issue or site specific documents that provide planning and design guidance for development assessment.

DCPs for mosquito hazard have been gazetted by three local authorities in northern NSW (Tweed, Byron and Ballina). Each recommends:

- Provision of general advice for residents and prospective developers;
- Identification of risk zones; and
- That major residential development proposals include a qualified and experienced entomologist in the consultancy team.

The DCPs acknowledge that on-site habitat modification may reduce biting insect breeding. However the opportunity to link rehabilitation of wetland function and delivery of other ecosystem services with mosquito source control is not developed into a recommendation.

Having outlined the planning situation and identified some problems with development that does not take account of ecosystem services and disservices we now present two illustrative case studies. The case studies demonstrate how restoration of ecological function can be a shared objective of both coastal wetland rehabilitation and saltwater mosquito hazard source control. One case study focuses on the development of a greenfield site and the other looks at a retrofit for an existing area adjacent to a degraded coastal wetland. Both are set in coastal peri-urban landscapes. These provide some guidance for new development planning and for retrofitting in established developments.

33.4 Case Studies

The case studies came from the first author's direct experience. In the first case study this was managing the planning approval processes on behalf of DPI Fisheries and in the second case study as a member of a team investigating wetland rehabilitation options at the site. Case study selection was made on the basis that they illustrated the two types of development occurring in the peri-urban coastal zone, new or greenfield site development and retrofitting components of an already developed site.

33.4.1 Case Study 1: Greenfield Site

In 2003 a 43 ha former cattle grazing property (Fig. 33.2) was the subject of a development application for 19 ha to be filled with imported earth, to create a ground level above flood height followed by construction of several hundred self-care dwellings with facilities for housing aged and disabled people (Fig. 33.3). The majority of the site is low lying, with natural ground level elevations measuring <1–2 m Australian Height Datum (AHD). Mean sea level is 0 m AHD, and the highest tides of the year occurring at the site reach 1 m AHD. During the 1970s

Fig. 33.2 The greenfield development site

Fig. 33.3 The proposal for several hundred self-care dwellings (Source: King & Campbell Pty Ltd, 2003)

surface and groundwater hydrology was modified to promote drainage for agricultural use. The natural waterways were deepened and straightened and floodgates were installed to control flow regimes. Floodgates are one-way valves installed across waterways to allow drainage from the site during low tides but preclude re-inundation by higher tides. This fragmented and degraded the coastal wetland. Part of the wetland was listed as a SEPP 14 Coastal Wetland in 1985. Grazing activities, causing periodic discharges of poor quality water with impacts on a nearby oyster farm and the broader estuary, continued until construction of the housing development commenced (Fig. 33.3).

33.4.2 Constraints and Approvals

The local authority responsible for determining the development application, Ballina Shire Council, used the Ballina Mosquito Management DCP (Ballina Shire Council 2003) to guide their assessment of the application. The DCP recommends the proponent use a qualified and experienced entomologist to incorporate relevant guidelines from the DCP into the application and ensure their effective implementation during construction. Recommendations in the DCP that became conditions of the local authority's approval mainly related to infrastructure (Ballina Shire Council 2004) and included:

- community buildings to be fully screened against mosquitoes;
- self-closing doors to be fitted at all points of entry; and
- screening structures to be installed over swimming pool and barbeque areas.

In addition to the DCP guidelines, the local authority mandated that prospective buyers of units within the development be notified and given access to the reports concerning mosquitoes prior to purchase (Ballina Shire Council 2004).

The proposal also triggered provisions within the NSW *Fisheries Management Act* 1994 requiring the application be referred to the fisheries agency for conditions of approval. The fisheries agency imposed additional conditions for better management of the wetland by:

- excluding development from occurring within a 100 m buffer between the mapped SEPP14 Wetland boundary and the development; and
- requiring preparation and implementation of a wetland rehabilitation and buffer management plan involving the removal of floodgate valves to promote tidal flushing.

These conditions aimed to achieve better management of the wetland. Because the mapped SEPP14 Wetland boundary did not encompass the whole wetland, the 100 m buffer circumscribed the wetland and provided an area where manipulations could be made to both rehabilitate wetland function and reduce the source of the mosquito hazard. Implementation of the wetland rehabilitation and buffer management plan had to commence during the early stages of the proposed development.

33.4.3 Lessons

Satisfying the conditions of approval required the developer to prepare and implement a rehabilitation management plan with planned and adaptive elements. Removal of one-way tidal floodgate valves enabled tidal inundation and introduced a more natural tidal hydrology into the wetland. Cessation of stock grazing at the site removed a disturbance stressor that had been degrading the wetland. Grazing in wetlands can exacerbate the mosquito hazard as hoof prints from stock walking in boggy sediments create a rough surface with hummocks for mosquito ovipositing and depressions that can be used as larval habitats.

The effect of site rehabilitation was a reduction in saltwater mosquito habitat (McGinn 2012). Reinstatement of tides partially restored hydrologic and sedimentary function within the wetland allowing silt to be deposited across the saltmarsh surface. Without the disturbance of stock grazing, this process continues to fill the old cattle hoof prints reducing larval habitat, while the increased frequency of tidal inundations reduces egg laying opportunities.

As work at the site progressed the wetland rehabilitation plan was adapted to incorporate installation of six channels for tidal flushing through an old levee to better link isolated pools. Removal of some river oaks (*Casuarina glauca*), a native pioneer plant species that had established on the levee, was required to ensure longevity of flushing channels. Future management of grey mangrove (*Avicennia marina*) and river oaks will be required to ensure flushing continues at a rate sufficient to minimise the mosquito hazard.

Restoration of tidal flushing was the key action that drove rehabilitation and provision of improved ecosystem services. Tidal inundation of saline water forms an additional service for the landowners as it is a cost effective weed suppressant along waterway margins at the site. Tidal inundation is compromised, however, by the small aperture of the culvert through which the tide is flushed. Thus, rehabilitation has been only partial but the site is still expected to provide more sustained delivery of ecosystem services rather than disservices. The system is not self-sustaining, however, and maintaining the improved conditions will require periodic management interventions. Planners and decision makers should appreciate that only achieving a portion of the total possible ecosystem service is a common outcome in urban areas (Bolund and Hunhammar 1999).

33.4.4 Case Study 2: Retrofitting Existing Development

A coastal mangrove wetland was directly impacted by urbanisation and the development of a nearby canal estate during the early 1980s (Fig. 33.4). With no buffer between the coastal wetlands and residential housing, degradation of coastal wetland habitat occurred. Today's residents experienced mosquito hazard and other disservices including odour, poor water quality, degraded vegetation and weed

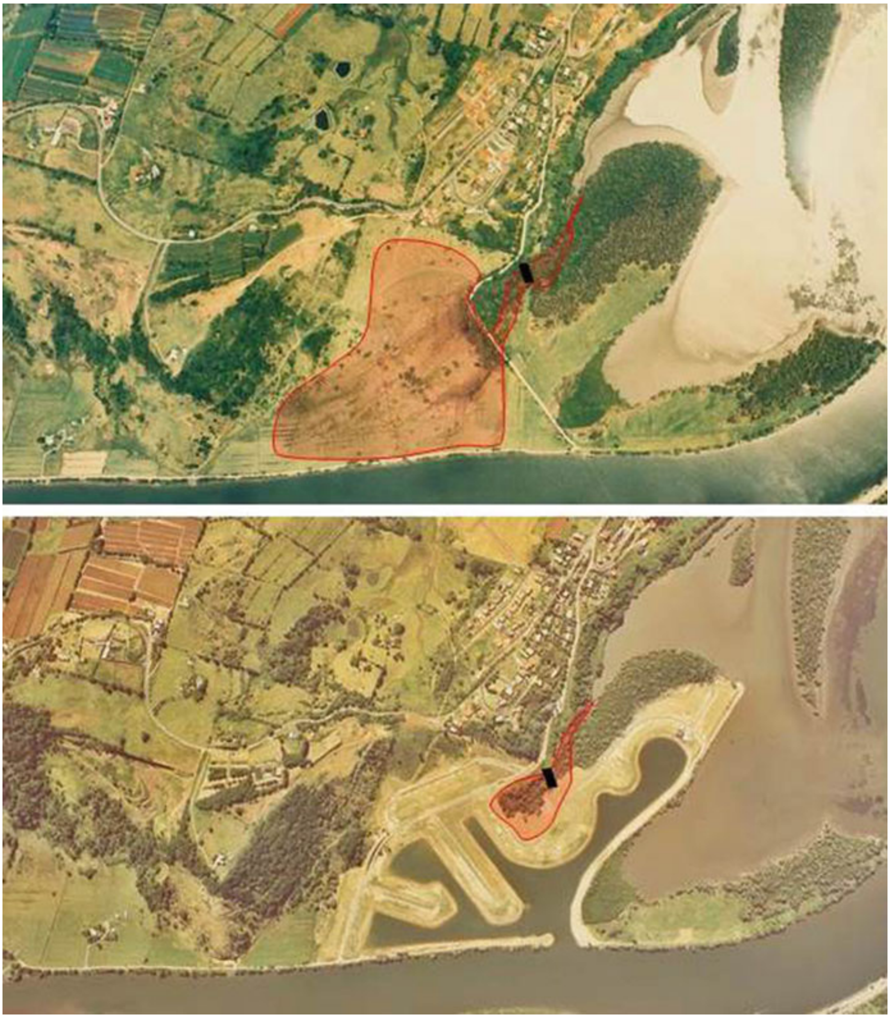

Fig. 33.4 Aerial photos from 1970s (top) and 1980s (bottom) showing the levee and catchment change that have contributed to the odour, poor water quality, weed incursion and mosquito hazard experienced by today's residents

incursions. The site has been regularly treated for the mosquito hazard via pelletised application of S-methoprene. However, persistent complaints from residents prompted Tweed Shire Council to consider a more holistic solution.

Preliminary investigations found part of the mangrove wetland to be poorly flushed due to a constructed levee across the tidal creek, limiting tidal exchange and creating an artificial back basin. The 0.4 m high levee is thought to be a legacy from the installation of overhead powerlines at the site in 1962. Subsequently, construction of an adjacent canal estate reduced the size of the catchment area of the waterway substantially, limiting catchment inflows and tidal amplitude (Fig. 33.4). Collectively, these works created a basin that is inundated by only the highest tides and by runoff from rainfall creating an ideal saltwater mosquito habitat.

33.4.5 Constraints and Approvals

To restore tidal flushing and rehabilitate ecosystem function at the site, with the purpose of improving ecosystem services and minimising disservices, Knight et al. (2013b) recommended that the Tweed Shire Council:

- reconnect the basin by modifying the level of the levee, and
- enhance tidal connectivity to:

  (a) manage mosquito production; and
  (b) restore system health.

These physical works triggered environmental assessment via a Review of Environmental Factors (REF) required by the *Environmental Planning and Assessment Act* 1979. The REF mandated management of potential acid sulfate soils, sediment and erosion control and other measures to avoid or minimise impacts of the proposed works. The REF process also identified that a conditional approval under the *Fisheries Management Act* 1994 was required. During the approval process the presence of major underground telecommunications cables in the vicinity of the levee was also identified. This delayed action and forced an assessment of how the physical works would be undertaken.

33.4.6 Lessons

Retrofit sites often require site specific tailored solutions. They require the specific mobilisation of plant and equipment in established areas where there are additional constraints on operations. Retrofit projects are rarely undertaken within a strategic framework and are often ad hoc in response to persistent public complaints. They often have limited funding available. Consequently, retrofit works often involve compromise. In this case study what was initially perceived as an obvious and easy solution became more complicated because of the legacy of historic and existing infrastructure. With each compromise the potential to actually improve on the degraded state favouring services rather than disservices should be re-evaluated. With this case study, while the constraint presented by the telecommunication cables was not identified until late in the planning process, its identification does demonstrate a strength of the existing regulatory and assessment framework.

33.5 Discussion

33.5.1 Constraints on Integrated Development and Mosquito Management

A framework of legislation and policy that constrains development within and adjacent to coastal wetlands is necessary for maintaining the valuable ecosystem services they provide. However, the existing framework can be perceived as a disincentive to restore degraded wetland function and improve ecosystem services. Similarly mosquito control agencies have found obtaining approvals to modify wetlands and use alternative environment-based approaches to reduce the mosquito hazard can be difficult (Webb et al. 2009; Dale and Knight 2012; Webb 2013). A trigger is needed within the existing framework of legislation and policy to assess the form, function and management of wetlands when adjacent lands are being developed. Further, it needs to promote (or require) action that reduces the mosquito hazard while also sustaining or rehabilitating coastal wetlands to favour the delivery of ecosystem services.

33.5.2 Local Government Planning Programs

Appropriate land use planning programs can make savings for local governments and their communities (Burby et al. 2000), but must address relevant problems. For peri-urban development in coastal areas planning programs need to consider population growth, mosquito hazard and wetland services. Assessment of development proposals adjacent to wetlands, including mosquito risk and management options, can be a catalyst for addressing orphan infrastructure and other legacies of former land uses. This should include correcting fractured ecological function and minimising the mosquito hazard. Investigations and assessments should consider the whole wetland as a single hydrologic unit rather than the extent of a planning zone or property boundary (Dale et al. 2010). Adopting a wetland hydrologic unit approach maximises both the environmental outcomes and benefits for new residents of developing peri-urban areas.

33.5.3 Codes to Ensure Sustainable Outcomes

Codes of practice can be used to outline activities that can and cannot be undertaken in coastal wetlands. They should identify wetland forms and rate their vulnerability to certain classes of activity. Where low risk activities are proposed, specific operating procedures tailored to specific wetland forms can outline the circumstances under which an activity can occur.

Codes should reflect the need for understanding of the vulnerability of wetland form and function to subtle changes in or beyond the wetland. Codes should facilitate wider application of well managed rehabilitation actions based on appropriate science. Codes should ensure that the development actions of proponents do not make things worse. They should set out the need for ongoing monitoring by landowners to facilitate adaptive management and preparedness to respond to unforeseen changes in wetland response. We also recommend that a code be developed which outlines how local authorities can, and should, maintain a register of wetland rehabilitation sites and a library of management strategies that have been employed.

33.5.4 Practical Considerations for Peri-Urban Areas

The majority of coastal greenfield development sites retain infrastructure or landscapes from their historic land uses. Ignoring or poorly managing these legacy features, particularly during land use change, can further degrade coastal wetlands, exacerbate mosquito hazards and potentially cause other disservices (odour, poor water quality, weeds, etc.). When ecosystem function is not considered during the development process, future residents may experience considerable cost in either tolerating the disservice or restoring the services (Niemelä et al. 2010). The cost of replacing lost or degraded ecosystem services should be taken into account in development decisions (Gomez-Baggethun and Barton 2013). Otherwise the desire amongst developers to avoid assessment and the risk of onerous conditions will continue to outweigh undertaking even low cost and small scale changes in wetland form that might improve wetland function.

Environmental assessment of new or developed sites in peri-urban coastal areas needs to focus on the relationship between wetland function and mosquito habitats. Understanding ecosystem function at the site is critical when considering the degree of intervention or rehabilitation of landscape needed to favour delivery of ecosystem services and reduce disservices.

33.6 Future Directions and Conclusion

In order to restore ecological processes, legislation, policy and guidelines are required to clarify what can be done in coastal wetlands, how it can be done and a robust and relatively simple procedure for permitting those activities. There are three areas that need to be considered. First, the misconception that some zoned and protected coastal wetlands do not require intervention to sustain or reinstate functional drivers needs to be addressed. This is particularly relevant during regulation and assessment of rehabilitation works and mosquito control activities. Second, codes need to take account of ecosystem functions with emphasis on hydrology and sedimentation in the wetland. Third, planning needs to trigger appropriate environmental assessment to include both ecosystem services and disservices both relating to longer-term impacts and the broader landscape context.

The two case studies demonstrated that restoration of ecological process can be a shared objective of both coastal wetland rehabilitation and saltwater mosquito hazard reduction. In coastal peri-urban areas, particularly, when greenfield sites with an adjacent mosquito hazard are proposed for development, planning frameworks should trigger assessment of ecosystem function with the desired outcome of strategies that address saltwater mosquito hazard and the rehabilitation of adjacent coastal wetlands.

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