An Analysis of Changes to Aquatic Habitats and Adjacent Land-use in the Downstream Portion of the Hawkesbury Nepean River over the Past Sixty Years

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Kylie Russell, Greg West and Bob Creese provided comments on the final draft.

NON-TECHNICAL SUMMARY

An Analysis of Changes to Aquatic Habitats and Adjacent Land-use in the Downstream Portion of the Hawkesbury Nepean River over the Past Sixty Years

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OBJECTIVE: to provide for the Hawkesbury Nepean Catchment Management Authority a framework within which to monitor the aquatic resources of the river

The AIMS by which the objective was to be achieved were to:

(a) deliver baseline data of current and historical distribution of native aquatic vegetation to satisfy Catchment Blueprint target requirements, and support National and NSW State of the Environment reporting processes, specifically mangrove, saltmarsh and seagrass communities,

(b) compile an historical assessment of the vegetated foreshores of the Hawkesbury River from Warragamba Dam to the river's mouth,

(c) deliver baseline data of current and historical distribution/condition of aquatic pest plant species, specifically *Caulerpa taxifolia* and *Egeria densa*,

(d) analyse the distribution data for native and pest species to deliver trend data, and scope the predictive capability between habitat change and land use pressure/resource management effectiveness,

(e) collate, manage and report data that might promote shared access and use by stakeholders under the auspices of the Hawkesbury Nepean Integrated Water Monitoring Framework,

(f) assess and interpret resulting spatial inventory of aquatic habitat/biodiversity resources to identify areas of the catchment that have management and conservation significance.

NON TECHNICAL SUMMARY:

The catchment of the Hawkesbury River is subject to urban development, agriculture, and recreational use, and because of these pressures some degradation of terrestrial and aquatic habitats is to be expected. For example, there has been a marked input of nutrients to this stretch of the river, and, with a lack of flushing because up to 90% of flow has been diverted for use within the Sydney metropolitan area, a number of changes would have been occurred to aquatic habitats.

To assist in understanding the nature and extent of these changes, a series of ortho-rectified historical aerial photographs of that part of the river from Warragamba Dam to the river's mouth was analysed. Within this stretch, 13 fixed locations were established, and within each location, six sites were set out. Features of interest in relation to disturbance of aquatic habitat over the past 60 years were identified in a geographic information system (GIS). The choice of locations and sites was biased towards situations where large-scale change could be detected, and hence are not

representative of the river as a whole. Fieldwork allowed the collection of data for a smaller scale of relevant habitat features.

The GIS analysis revealed that, except for the upper portion of the study area, natural vegetation was stable at most locations. Widespread, but variable degrees of loss of agricultural land were seen, with reductions recorded in 11 of the 13 sampling locations. A complete extinction of agricultural land occurred at Pittwater, and small losses were seen in the middle stretch of the study area. Residential area was present in 12 of the 13 locations, and at 11 of these 12 locations an increase in extent was seen. Areas developed for industrial activity increased in the upper river locations. An increase in formal passive recreation area was seen at seven locations.

With regard to aquatic features, there was an overall change in their distribution. Seagrass was present at five locations, but was lost at three of these, stable at a fourth and increased substantially at the fifth. Mangrove was present at eight locations and increased over time at all of these. The cover of saltmarsh, recently declared a Threatened Ecological Community, decreased at all of the seven locations at which it was present.

On the basis of field surveys and other information, it was possible to comment on the distribution of the native freshwater macrophyte *Vallisneria gigantea* and a series of aquatic weeds, including those that live in salty environments (*Caulerpa taxifolia* and *Juncus acutus*) and others that exist in freshwater (*Egeria densa, Salvinia molesta, Salyx* spp.)

Some management implications are brought forward. These are based on the broad trends in change in land use, the likely impact of these trends on freshwater and estuarine habitat, the conservation of species considered to be “sensitive”, and the removal of exotic and invasive species such as *Juncus acutus*.

1. INTRODUCTION

1.1. Background

Fish, crustaceans, and molluscs are integral components of freshwater, estuarine and marine ecosystems, and some of the species in these groups add to the value of local and regional economies. Other aquatic species, not harvested because of their small size, make indirect contributions, as they are part of the food chain. To conserve the harvested as well as the other species, and/or enhance the economies that depend on them, it is necessary to have conservation policies not only for the animals but also for the habitats in which the animals live. Unfortunately, two centuries ago as the colony of NSW expanded into the catchment of the Hawkesbury River, aquatic habitats were degraded due to logging and then the development of agriculture. Subsequently, additional habitat was disturbed due to the installation of infrastructure for urban and industrial needs. This infrastructure facilitated the harvest of fresh water, discharge of effluent and stormwater, and the mining of sand. With the advent of the Hawkesbury Nepean Catchment Management Authority it is appropriate to review aspects of change in habitat over past decades, assess the Catchment Action Plan for the river, and, where necessary, set in train appropriate on-ground rehabilitation activities.

We analysed large-scale change in land use over the past several decades that had occurred between Warragamba Dam and Broken Bay including Pittwater. It was envisioned that changes in land use might relate to measurable changes in aquatic habitats.

The main driver that modifies aquatic habitats is a decrease in natural vegetation, which causes an increase in the discharge of stormwater, in turn enhancing the discharge of sediments and nutrients. Clearing for agricultural land, followed by further modification in the form of urban and industrial landscapes, initiates this process. The process of modification can also give rise to the discharge of other pollutants. Enhanced stormwater flows can erode stream and river banks, and increased sedimentation can smother native freshwater vegetation and seagrass. Nutrient enrichment can increase algal densities, reducing light levels through the water column and hence reducing photosynthesis of native aquatic plants such as seagrass growing on the bottom. Greater stormwater flow, greater amounts of nutrients and new pollutants can also adversely affect saltmarsh and mangrove, but for the mangrove the deposition of sediment can create new opportunities for settlement.

In other situations where dams are installed to harvest water, some of the above disturbances can be further enhanced due to reduction in flow and hence reduced flushing capacity. Pollutant residence times can increase, and saltwater penetration can be magnified.

Loss of seagrass has been reported in a number of estuaries in NSW (Appendix 1). Even though in some cases where comparisons were based on data derived from two different methods, losses were exceptionally large, exceeding 40%. In other studies, where a consistent analytical technique was used, the results were unequivocal with large losses being reported (e.g., Williams and Meehan 2004).

Major changes in land use can be accompanied by smaller modifications that include the creation of infrastructure such as roads and dams, or recreation facilities. Many large-scale and some medium-scale changes can be observed and mapped by inspection of a succession of aerial photographs. Unfortunately, aerial photos may not capture small-scale events such as the presence of eroded bank or weeds, or the installation of pumps. Some of the latter features, between Warragamba Dam and Wisemans Ferry, have been mapped by West *et al*. (in prep.).

1.2. Need

To our knowledge there are no thematic maps of change in land use in the Hawkesbury Nepean catchment. Maps of this type have immense value in quantifying the degree of change that has occurred as well as the timeframe over which such change has occurred. The latter is particularly important as change may have taken place in the distant past and the environment has since stabilized, mandating a different management approach to situations in which change may have recently started to escalate. An understanding of change in land use informs the conservation and management needs of aquatic habitats.

The vegetation of the estuarine portion of the Hawkesbury River was first mapped in the early 1980s (West *et al.* 1985). Mapping of estuarine vegetation for the Berowra and Marramarra Creek subcatchments was undertaken by Williams and Watford (1997), and for Cowan Creek by Williams and Watford (1999). Nevertheless, regular and comprehensive updating of maps is desirable given increases in population and likely changes in land use. In the late 1990s, at the request of the then Hawkesbury Nepean Catchment Management Trust and on the basis of anecdotal reports of variation in the distribution of aquatic vegetation, the then NSW Fisheries remapped the estuarine portion of the waterway (G. West, unpublished a and b). Some changes were obvious (Table 1a and 1b), even given that the earlier map was created by the *camera lucida* technique, an inherently less accurate procedure compared to the analysis of aerial photographs within a geographic information system (GIS).

1.2.1. Seagrass

Seagrass has been shown to be the basis of strong ecological links with many species of fish, particularly those of commercial and recreational significance. Strong management plans are needed to conserve and/or enhance the seagrass that currently exists in the Hawkesbury River. Table 1a indicates that loss of seagrass in the lower portion of the River over the past two decades has been substantial (-19%). In contrast, the situation in Pittwater is more stable (Table 1b).

1.2.2. Mangrove

Mangrove trees make a significant contribution to estuarine productivity due to the provision of habitat as well as the production of detritus. Saintilan and Williams (1999, 2000) showed a strong trend for increase in area of mangrove for the whole of southeast Australia. Tables 1a and 1b suggest this is not the case for either the Hawkesbury River or Pittwater where losses of mangrove have occurred (-13% and -31%, respectively). Within Pittwater, however, at Careel Bay, a gain in mangrove has been recorded (Wilton 1998).

1.2.3. Saltmarsh

Recently, saltmarsh in NSW was listed as a Threatened Ecological Community under the NSW Threatened Species Act (NSW Scientific Committee 2004). Investigations into the Georges River (Kelleway 2005) reveal substantial damage from vehicles and trampling. The situation in the Hawkesbury River is unknown although Table 1a suggests a large gain in saltmarsh has taken place over the past 20 years, an outcome that is most probably an artefact, as our experience in mapping change in saltmarsh shows no such expansion at other estuaries over a similar time frame. More likely, the method used by West *et al*. (1985) underestimated the extent of saltmarsh some years ago. GIS facilities provide a more accurate way by which to map the macrophytes of estuaries (Meehan *et al*. 2005). In contrast, the situation at Pittwater suggests a substantial loss (-15%) of saltmarsh (Table 1b). If the baseline data were underestimated with the methodology of the day, that apparent loss might actually be larger.

Another issue in relation to saltmarsh is the variety of species present. Pickthall *et al*. (2004) gave special attention to *Selleria radicans*, *Gahnia fillum*, and *Wilsonia backhousei* in the Georges River due to their restricted distribution and limited abundance. In the Parramatta River, Kelleway *et al*. (2007) recognise a similar situation for these species as well as for *Lampranthus tegens*. The distribution and abundance of these four species in the Hawkesbury River is unknown.

Any changes in the distribution of seagrass, mangrove and saltmarsh need to be correlated with changes in land use, and hypotheses generated about these interactions.

In regard to the freshwater aquatic vegetation of the Hawkesbury Nepean system, to our knowledge, the distribution of relevant species has only been mapped in recent times (Appendix 2a and 2b). Without a regular remapping program it is difficult to gain any insight into distributional changes for the freshwater plant species.

Table 1a. Trend of cover of seagrass, mangrove, and saltmarsh in the Hawkesbury River over recent decades.

Hawkesbury River	**West *et al*. (1985)**	**West, G. (unpub.)**	**% change**
Photo year and scale	1976 – 1:25 000 1977/78 – 1:25 000 1979 – 1:16 000 1979 – 1:40 000	1997 – 1:16 000	
Method	*Camera lucida*	GIS	
Field inspection	August 1981, May and June 1982	July 2000	
Seagrass (ha)	47.0	38.1	-18.9%
Mangrove (ha)	1,065.4	926.4	-13.0%
Saltmarsh (ha)	112.6	239.7	+112.8%

Table 1b. Trend of cover of seagrass, mangrove, and saltmarsh in Pittwater over recent decades.

Pittwater	**West *et al*. (1985)**	**West, G. (unpub.)**	**% change**
Photo year and scale	1977 – 78 – 1:25 000	1997 – 1:16 000	
Method	*Camera lucida*	GIS	
Field inspection	August 1981	July 2000	
Seagrass (ha)	193.4	191.5	-1.0%
Mangrove (ha)	18.0	12.5	-30.5%
Saltmarsh (ha)	2.6	2.2	-15.4%

1.2.4. Aquatic weeds

There are many species of weeds associated with aquatic environments. In the estuarine portion of the Hawkesbury River these include the alga Caulerpa (*Caulerpa taxifolia*) and the sedge known as Spiny Rush (*Juncus acutus*). Extensive public education campaigns are underway for Caulerpa by NSW DPI, but the Spiny Rush is less well documented in terms of its distribution and need for control.

More is known about the threats posed by species found in and adjacent to the freshwater reaches due in part to the efforts of the Commonwealth Research Centre for Australian Weed Management (CRC-AWM). The Centre has identified a number of "Weeds of National Significance" such as Alligator weed (*Alternanthera philoxeroides*; CRC-AWM, 2003a), Cabomba (*Cabomba caroliniana*; CRC-AWM, 2003b), Salvinia (*Salvinia molesta*; CRC-AWM, 2003c) and Willow (*Salix* species; CRC-AWM, 2003d). One weed that is not on the Centre's list, perhaps because of limited distribution Australia-wide, is Egeria (*Egeria densa*). Nevertheless, Egeria has become a particular problem in parts of the Hawkesbury River from Menangle to Warragamba Dam, and from the dam downstream to Sackville in recent years (E. Taylor-Wood, pers. comm., 2006).

Another group of plants are on the "Alert List for Environmental Weeds". Three of these are terrestrial: Cyperus (*Cyperus teneristolon*; CRC-AWM, 2003e), Horsetails (*Equisetum* species; CRC-AWM, 2003f), Subterranean Cape Sedge (*Trianoptiles solitaria*; CRC-AWM, 2003h), while a fourth, Lagarosiphon (*Lagarosiphon major*; CRC-AWM, 2003g), is an aquatic plant that can dominate dams, slow-moving streams and lakes. The impact on plants deemed desirable to sustain biodiversity, as well as the financial investment necessary for weed control, suggests the distributional data for the Weeds of National Significance and for the weeds on the Environmental Alert List needs to be regularly assessed.

The contribution of freshwater macrophytes, seagrass, mangrove and saltmarsh to aquatic productivity, and the reverse impact of weeds and inappropriate land use, or controls on land use, need to be recognised within catchment planning for the Hawkesbury Nepean, as well as other river systems. The objective of this exercise was to provide for the Hawkesbury Nepean Catchment Management Authority a framework within which to monitor the aquatic resources of the river.

2. METHODS

2.1. Study site

The size of the Hawkesbury Nepean catchment is 22,000 km^2, with the portion of the catchment downstream of Warragamba Dam being relatively small. The estuarine section is approximately 5,000 ha in area, or 0.2% of the total, but the estuary receives much of the upstream runoff in the form of sediments and pollutants, and is dependent on flooding and tidal flushes to remove these inputs.

Thirteen locations were chosen along the river from the Warragamba Dam to Broken Bay (Figure 1). Six sites were selected within each location and at each site a study zone running 500m into the hinterland was established. Cover of vegetation and land use within the study zone and the adjacent water were tracked through time using archived aerial photographs.

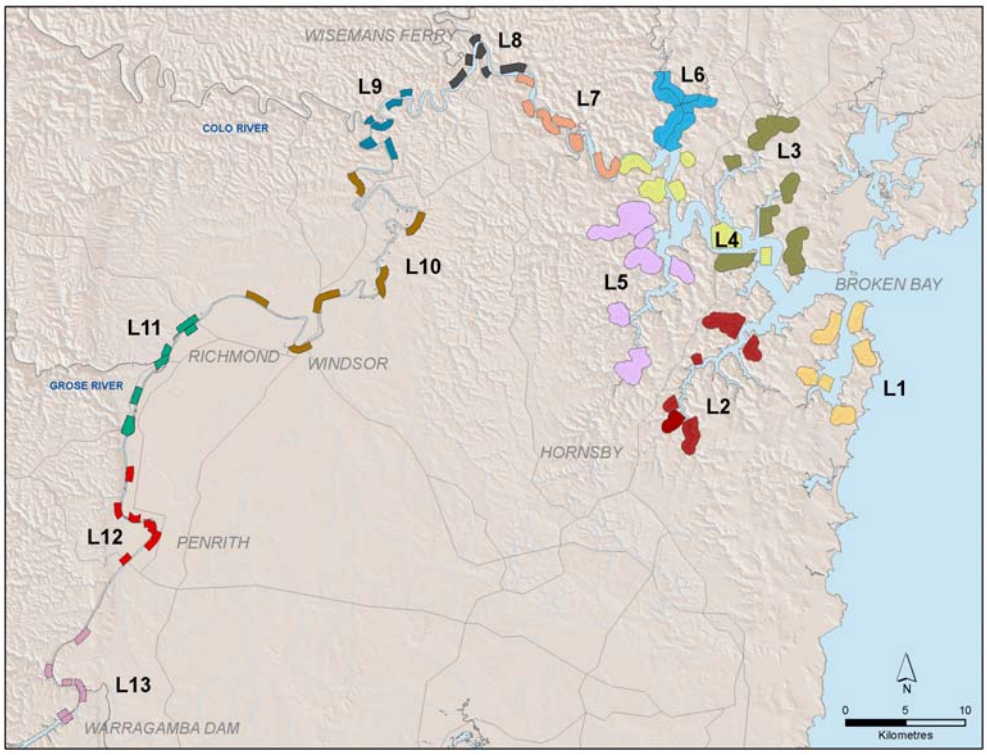

Figure 1. Map of locations and sites. The different colours represent the positions of the six sites within each of the 13 locations.

2.2. Laboratory work

It was originally hoped to use airphotos from every decade from the present to the 1930s. Due to the lack of photo coverage in the 1930s, that decade had to be abandoned. The analytical time necessary to digitise the boundaries between features of interest in the more recent photographs meant that airphotos from the 1960s and 1970s could not be examined within the timeframe of the project.

Consequently, photos from the 1940s, 1950s, 1980s, 1990s, and 2000s were examined. The spatial extent of the 13 Locations (Warragamba to Pittwater) meant that for any particular decade it was not always possible to get photo runs from a single year. When possible, consecutive years were chosen. Over 300 aerial photos (in the form of contact prints) were used in this study (Appendix 3). Some were obtained from Hornsby Shire Council, Gosford City Council, Gosford Library, and Baulkham Hills Council, and other photos were accessed from the archives of NSW DPI-Fisheries. Some photos had to be purchased from United Photo & Graphic Services (Melbourne, Victoria) or from NSW Land and Property Information. For the 2000s, a photo-mosaic electronic image provided by Hornsby City Council was used to examine some of the study sites.

Airphotos were incorporated into the GIS by the processes of scanning and then ortho-rectification. Scanning was done on an A3 flatbed scanner at 600 pixels per inch (ppi). Ortho-rectification was carried out on the scanned images using Erdas Imagine 8.6 and the systematic errors resulting from camera geometry were removed using the camera model. The inclusion of a Digital Elevation Model (DEM) enabled the removal of errors resulting from topographic displacement. The resulting digital images were geo-referenced to the NSW Digital Topographic Database (DTDB) and re-sampled to have a final resolution of 1m. The map projection used was GDA 94 and the referencing zone was MGA 94, Zone 56. For the older photos (1940s and 1950s) the camera model could not be applied and the polynomial model (2^{nd} order) was used. The fiducial error, the number of ground control points and the RMS error obtained for each rectified photo were systematically recorded and are summarised in Appendix 4.

Features of interest were mapped via onscreen digitising using Arcmap (ArcGIS 9.0 and 9.1). The boundaries of natural vegetation as well as agricultural land, residential land, industrial land, and features such as parks within the 500-metre "buffer zone" were identified. The boundaries of intertidal saltmarsh and mangrove, and subtidal seagrasses were digitised.

The quality of aerial photos varied, and understandably the quality of old photos were often poorer than photos of more recent decades; problems with glare on the surface of the water were encountered which in some cases prevented the mapping of seagrass (Figure 2).

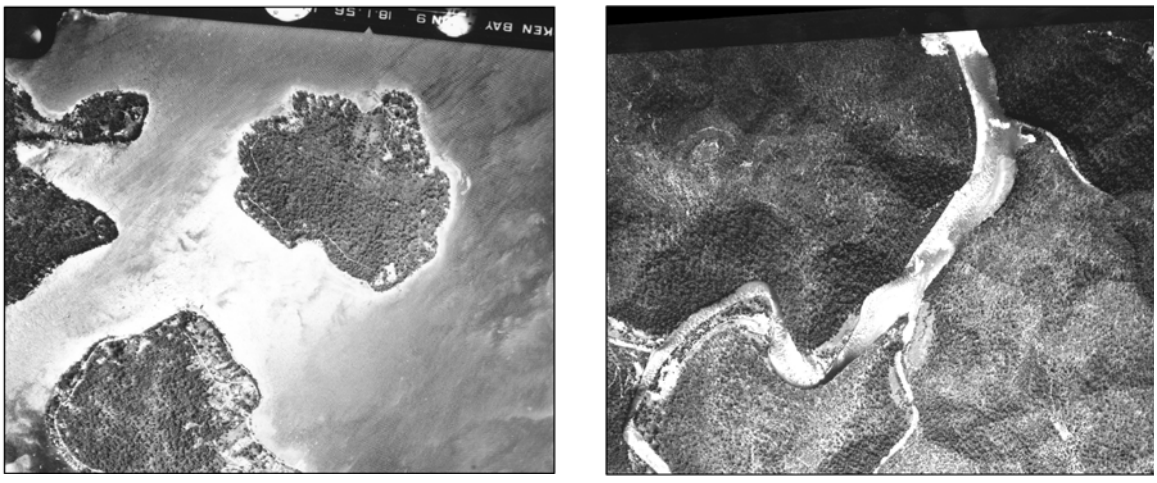

Figure 2. Sun glint as a limitation on the analysis of aerial photos at Scotland Island, 1955 (left) and Berowra Creek, 1955 (right).

To ensure consistent spatial accuracy, all digitising was carried out at an onscreen scale of 1: 3000. Images were enhanced with filtering techniques to highlight variations in cover and texture of

features such as native vegetation and mangroves. Once digitising was complete, the area in hectares for each feature was then calculated. Where a feature was so small as to not be observable in a photo, but its extent was seen to expand over time in subsequent photos, an arbitrary value of 0.1 hectare was assigned in order to generate a figure in Table 3 by which to determine percentage increase.

Fourteen types of land use and/or habitat were identified within four major categories. The first major category was type of land use and included natural vegetation, agricultural land, industrial area, and residential area. The second category focused on unvegetated land and examined the extent of bare sand, bare earth and dry riverbed. The third category dealt with constructed infrastructure including reservoirs, roads and dam walls, as well as formal passive recreation areas (golf courses and parks). A fourth category was established to encompass estuarine vegetation – seagrass, mangrove, and saltmarsh.

2.3. Fieldwork

The digital base map (presumptive map) created for the 2000s was taken into the field for validation, and a real-time mapping system was used to annotate the base map. Field equipment included position locating facilities (DGPS) and sounder in a small boat. The presumptive map was subsequently modified where necessary using the field data.

2.4. Quality control

The utility of historical photos becomes an important consideration given that no fieldwork was done in earlier years to confirm the boundaries of vegetation and other features. To assist in resolving the accuracy of present-day assessments of historical occurrence, target features mapped from the photos from the 2000s for the seven most downstream locations were compared with areas that had been field checked and modified. A table was created, and increases or decreases in area of the features, relative to the field-corrected map, were added. In all cases the variation between the before and after field validation calculations were extremely small (Table 2, Appendix 5); the field validation brought a mean addition of 0.91 hectares and a mean subtraction of 0.45 hectares for the affected features.

The main feature that decreased in extent after field validation was natural vegetation, but this trend was mirrored by an increase in the cover of mangroves, and reflects the fact that some trees assumed to fall within the category of natural vegetation on the aerial photos ended up being mangroves when checked in the field. The increase in seagrass beds is mainly due to small seagrass patches not visible from aerial photos.

A metadata statement is included to summarise technical aspects of the project (Appendix 6).

The intent of the project was to generate observations about change in habitats adjacent to the Hawkesbury River. A further step, not taken at this stage, would be to establish correlations between changes of various types. It is not possible to create definitive conclusions about cause and effect in hindsight; these would need explicit experimental designs in relation to future modifications of the catchment.

3. RESULTS

On the premise that the major driver of change in land use in the environs of the Sydney metropolitan region is increase in population, we present our analysis firstly in relation to the 14 nominated types of land use and habitat, and then in relation to each of the 13 study locations. A series of tables are presented, some in the form of appendices that contain the base data, and others as summary tables in the text. The first of the summary tables shows change in cover in percentage terms from the earliest date at which photos were available to the most current date (Table 3). While in some cases percentage change is quite large, the absolute amount of change might be relatively small, and vice versa. For example, there was a 511% increase in area of seagrass at Location 4, but as an absolute amount this was an increase from 2.29 ha to 14.00 ha. Therefore, once data on percentage change are presented, a second table (Table 4) is set out to examine the extent of change in absolute terms. Appendix 7 shows the raw data from which these summary figures were derived.

3.1. Change in land use and habitat between the 1940s and 2000s

Fourteen types of land use and habitat were identified. Percent change for the variation in area of these categories from the 1940s and 2000s is set out in Table 3 and highlights from the table follow. Not all 14 categories are present at each of the 13 locations. Due to the gaps between locations, there is no attempt to summarise change in land use across the whole of the study area.

Natural vegetation – Cover of this category was tracked at all locations. It effectively did not change at six locations (<10% increase at Locations 2, 3, 5 and 6, <10% decrease at Locations 4, 8 and 13,), showed a substantial loss at Location 1 (43%), and otherwise showed a wide range of gains (from 17% at Location 9 to 266% at Location 11). “Natural vegetation” in this study refers to any riparian vegetation, forest, or woodland, and so the broad definition of the term may in part cause this wide range of changes.

Agricultural land – At 11 of the 12 locations containing this category of land use, a loss of agricultural land was seen. The exception is Location 13 where it increased substantially. Losses were slight at Locations 6, 8 (<5%) and 7 (10%), were more substantial at Locations 9 (17%) and 10 (16%), and were extensive at Locations 4 (39%), 5 (32%) and 11 (47%). Complete or near-complete loss was seen at three locations: Location – 100%, Location 3 – 98%, Location 12 – 77%.

Residential area – This land use showed a loss at Location 8. Increases were seen at the other eleven locations, with modest change at Locations 9 (9%) and 10 (20%), and progressively larger changes elsewhere: 98% at Location 3, 117% at Location 13, 164% at Location 4 (predominantly on Dangar Island), 347% at Location 1, 501% at Location 12, and 569% at Location 5 with highest increases at Location 6, 7 and 11.

Industrial area – Change in industrial area was major at Location 11 (>1000%), and showed a small increase at Location 12 (29%).

Formal passive recreation areas (*golf courses and parks*) – Increases in amount of land dedicated to this type of use was seen at seven locations (Locations 1, 2, 3, 4, 8, 12 and 13). The increases ranged from 283% at Location 1 up to more than 1000% at Locations 2, 4, 12, and 13.

Bare sand – Large losses of bare sand were seen at Locations 1 and 4, but an increase was noted at Location 3.

Bare earth – Large losses of bare earth were seen at Locations 11 and 13.

Dry riverbed – All of the dry riverbed was lost at Location 12 but its extent increased greatly at Location 13.

Reservoir – Modest changes were seen in reservoir extent at Locations 8 and 9, but a large loss was seen at Location 10. Location 11 showed an important increase due to the creation of a new reservoir in the 1980s.

Roads – An increase in roads was seen at Location 3 with a very large increase at Location 4.

Dam wall – The increase in dam wall at Warragamba (Location 13) was major, due to the augmentation of the previously smaller facility.

Seagrass – Seagrass is an important component in the mix of habitats in estuaries. It was found in five locations and showed a high degree of variability in change in cover, from little change at Location 3 to a substantial loss at Location 5 (81%) and a five fold gain at Location 4 (511%).

Mangrove – Occurring at eight locations, this habitat type is comprised of two species, neither of which was discriminated in this study. The river mangrove *Aegiceras corniculatum* occurs upstream in fresher waters than the grey mangrove *Avicennia marina*. Extension of cover of mangrove occurred in all eight locations, from very modest amounts (11% in Location 2) to a doubling in cover at two locations (121% at Location 1 and 108% at Location 7).

Saltmarsh – This type of vegetation is comprised of a number of species, is present at a slightly higher elevation than mangrove and is sometimes invaded by the latter. It has been declared a Threatened Ecological Community under the NSW Threatened Species Act, and is at risk in relation to rise in sealevel. Saltmarsh was present at seven locations and suffered major losses at all of them (51% – 96%).

Change in type of land use did not necessarily follow the general trends set out in terms of the above percentage summaries. Such situations are set out in the following sections.

Table 2. Quality control exercise: Comparison of classification (ha) for the 2000s before and after field validation by Location. Increases are shown in blue text, decreases in red.

	Natural vegetation	Agricultural land	Residential area	Industrial area	Passive Recreational area	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
Location 1														
2000s	403.22	0.00	506.37		77.30	17.91						157.85	16.32	1.45
After field validation	403.22	0.00	506.37		77.30	17.91						161.34	16.46	1.45
Location 2														
2000s	1336.33				5.53							2.71	14.10	0.30
After field validation	1335.71				5.53							3.80	14.73	0.30
Location 3														
2000s	1651.55	0.68	65.00		10.03	6.27				8.29		34.69	120.84	13.60
After field validation	1650.40	0.68	65.00		10.03	6.27				8.29		34.89	121.96	13.60
Location 4														
2000s	619.67	41.14	73.84		4.18	0.00				10.31		14.00	191.00	38.78
After field validation	619.56	41.14	73.84		4.18	0.00				10.31		14.84	191.11	38.78
Location 5														
2000s	2342.24	15.04	3.36									2.53	179.15	8.55
After field validation	2341.93	14.84	3.36									3.78	179.86	8.35
Location 6														
2000s	869.34	108.36	21.69							4.46			218.98	110.93
After field validation	868.91	108.36	21.69							4.46			219.73	110.93
Location 7														
2000s	335.52	274.82	15.93										79.91	9.87
After field validation	334.98	274.82	15.93										80.45	9.87

3.2. Change at respective locations between the 1940s and the 2000s

Location 1 – Change at this location (Figure 3) was characterised by a large loss (>40%) of natural vegetation and the complete loss of agricultural land. Passive recreation area in the form of parkland and golf course increased substantially at this location (282%). Bare sand that was observed at Barrenjoey (Location 1, Site 1) disappeared due to what appears to be a revegetation program. Large losses in saltmarsh (96%) and seagrass (29%) were paralleled by the largest gain in mangrove for the whole of the location (121%).

Location 2 – Amenity facilities in the form of parkland (>1000% increase since the 1940s) were installed at this location (Figure 4). Other changes were characterised by a large loss in saltmarsh (91%) and seagrass (42%), and a small gain in mangrove (11%).

Location 3 – Change at this location (Figure 5) was characterised by an almost complete loss of agricultural land (98%) but nearly no change in natural vegetation. The amount of residential area doubled. A large loss in saltmarsh (69%) was coupled with a gain in mangrove (39%), but seagrass area was little changed. Amenity facilities in the form of parkland increased considerably in percentage terms at this location (334%), particularly at Site 5.

Location 4 – Change at this location was characterised by a relatively large loss of agricultural land (39%) but little change in natural vegetation (Figure 6). The amount of residential area more than doubled (164%). Percentage-wise, an enormous increase in seagrass was seen (>500%), due almost entirely to large expansions around Scotland Island (Site 1). A substantial increase in mangrove (89%) was also observed. The area of saltmarsh decreased (60%).

Location 5 – Change at this location (Figure 7) was characterised by a very large increase in residential area (569%), but little change in natural vegetation. However, the large percentage increase actually represents only a rise from an unmeasurable amount to 2.1 ha at Site 4 (see Appendix 7). Loss of agricultural land was modest (32%). Large losses in seagrass (81%) and saltmarsh (79%) were complemented by a moderate gain in mangrove (25%).

Location 6 – Development of residential area was considerable at this location (Figure 8). A small increase in natural vegetation was observed (7%). Seagrass does not grow at this part of the river, but half of the saltmarsh was lost (51%) and a substantial gain in mangrove occurred (34%). There was little loss in agricultural land.

Location 7 – Residential area increased significantly at Location 7 (Figure 9). A small increase in natural vegetation was observed (10%). More than half of the saltmarsh was lost (68%) and a doubling of mangrove was measured (108%). There was a small loss of agricultural land (10%).

Location 8 – Airphotos were not available to examine land cover in the 1940s (Figure 10). Photos from the 1980s show a decrease in residential area (24%) but an increase in amenity (golf course, 34%). Mangrove increased by a third (31%). Little change was seen in the amount of natural vegetation, agricultural land or reservoir.

Location 9 – Photos for this location were not available for either the 1940s or the 1950s, but photos from the 1980s show a small increase in residential area (9%), and a modest increase in natural vegetation (Figure 11). Agricultural land decreased somewhat (17%).

Location 10 – Problems were encountered obtaining photos for this location for the earlier decades. The losses of agricultural land (16%) and reservoir (77%) were paralleled by gains in the cover of natural vegetation (29%) and residential area (20%) (Figure 12).

Location 11 – A very large increase occurred in the cover of natural vegetation (266%), and half of the agricultural land was lost (47%) (Figure 13). Development of residential and industrial areas was very significant.

Location 12 – Change at this location (Figure 14) was characterised by an enormous increase in residential area (501%). A large increase in natural vegetation (191%) was measured. Most of the agricultural land was lost (77%), as well as all of the dry riverbed. An increase in industrial area was measured (29%).

Location 13 – Residential area doubled (117%) and there was a small loss of natural vegetation (10%) (Figure 15).

More detailed inspection of each of the six sites at each location is possible by magnifying the respective images, but the preparation and inclusion of a map for each of the 78 sites (13 locations x six sites per location) was considered unnecessary at this stage. As the relevant shapefiles have been provided as part of this report, it is possible to create, examine and manipulate whatever images are considered necessary.

As examples, figures are included to represent scaled-up images for three sites chosen to represent the entrance, middle river and upper river sites within the study area. Figure 16 depicts Site 2 at Location 1 (Careel Bay at Pittwater). Natural vegetation has all but disappeared and little saltmarsh remains. The cover of seagrass has not varied appreciably, but mangrove has greatly increased its presence. A large park is present in the middle of the site.

Figure 17 shows Site 2 at Location 7 (Gunderman) where multiple changes can be observed. There was a reduction in natural vegetation in two distinct ways: numerous small patches within agricultural land have disappeared; a single large area to the northwest has been overtaken by residential land. The area of agricultural land appears not to have changed, but the cover of saltmarsh is much reduced. A large increase in mangrove is evident to the point where the channel has been noticeably constricted on the east and west sides of the peninsula.

Figure 18 is a representation of Site 6 at Location 12 (Penrith) where the Great Western Highway crosses the Hawkesbury River. While foreshore vegetation is still present, the previous agricultural land has been replaced with residential properties, parkland and golf course.

Table 3. Percentage change in land cover and habitat between the 1940s (or 1980s *) and 2000s. Negative change is in red. A blank cell indicates that the feature of interest was not present. # indicates situations in which the area of a given land use category or habitat type was assumed in the earliest of aerial photographs to be 0.1 ha for the purpose of calculation. To cater for analytical error in the processing and analysis of aerial photographs, small changes are shown as less than 5%.

	Natural vegetation	Agricultural land	Residential area	Industrial area	Passive recreational area	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
L1	-43.32	-100.00	347.32		282.30	-65.64						-28.30	120.54	-95.98
L2	<5				>1000#							-42.46	10.59	-91.45
L3	<5	-97.73	97.69		334.20	21.28				73.79		<5	38.63	-68.55
L4	-5.71	-38.84	164.00		>1000#	-100.00				>1000#		511.35	88.72	-60.11
L5	<5	-32.07	569.49									-81.38	25.04	-78.98
L6	6.52	<- 5	>1000#							-10.98			34.29	-50.80
L7	10.38	-9.53	>1000#										107.83	-67.76
L8 *	<- 5	<- 5	-23.87		33.77				<- 5				30.96	
L9 *	17.21	-16.77	8.53						5.84					
L10 *	28.99	-16.49	19.53						-77.20					
L11	266.49	-46.53	>1000#	>1000#			-68.95		>1000#					
L12	190.70	-77.18	500.77	28.85	>1000#			-100.00						
L13	-10.40	>1000#	117.35		>1000#	0.00	-75.58	>1000#			>1000#			

3.3. Nature of change

In most cases change in extent of cover was tracked as persistently positive or negative. However, in some cases change was variable, and for this reason the data showing the actual change in cover for any given type per decade, rather than overall percentage change, are set out in Table 4. Inspection of the data showed some situations where change did not follow a constant path. On six occasions change peaked at various times (labelled “high period”) and then fell away, while in three circumstances the reverse took place (“low period; Table 5). In four situations change was variable over time. For example, cover of seagrass was at its maximum in Location 3 in the 1980s, while the cover of natural vegetation at Location 12 was at its lowest in the 1950s. The amount of land in agricultural use at Locations 6 and 7 varied over time.

There was no decade in which change consistently hit a peak or fell to a trough. All troughs, for natural vegetation at Locations 4, 9 and 12, implied that this type of cover has increased in the 2000s relative to what was present in the 1980s, 1990s and 1950s, respectively. It is worth noting that the peaks and troughs shown in the 1980s could have possibly occurred in the 1960s or 1970s, as this project was unable to map those decades.

Table 4. Change in land cover and habitat (ha) by Location. NM (Not Mappable) refers to the poor quality of some aerial photos that prevented the mapping of certain features; NA (Not Available) refers to the unavailability of aerial photos for a particular year or section of the river.

	Natural vegetation	Agricultural land	Residential area	Industrial area	Passive Recreational area	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
Location 1														
1940s	711.44	93.89	113.20		20.22	52.13						220.16	7.40	36.03
1950s	599.10	40.01	252.93		42.24	NM						NM	14.05	32.84
1980s	401.44	0.00	496.99		79.69	42.72						196.47	15.19	1.64
1990s	398.90	0.00	504.58		78.58	29.72						169.99	14.55	2.26
2000s	403.22	0.00	506.37		77.30	17.91						157.85	16.32	1.45
Location 2														
1940s	1330.05				0.00							4.71	12.75	3.51
1950s	1329.50				2.30							4.36	13.61	2.13
1980s	1331.12				5.65							4.43	16.27	0.38
1990s	1331.64				5.55							3.13	15.66	0.26
2000s	1336.33				5.53							2.71	14.10	0.30
Location 3														
1940s	1650.92	29.92	32.88		2.31	5.17				4.77		33.37	87.17	43.24
1950s	1652.51	14.28	47.71		3.07	5.80				5.50		36.15	88.21	36.34
1980s	1649.69	1.18	52.38		10.26	9.08				8.52		38.32	113.74	21.53
1990s	1651.39	0.89	63.21		11.06	6.62				8.95		34.76	114.03	14.80
2000s	1651.55	0.68	65.00		10.03	6.27				8.29		34.69	120.84	13.60
Location 4														
1940s	657.16	67.27	27.97		0.00	0.40				0.00		2.29	101.21	97.22
1950s	610.95	82.18	37.85		0.00	0.00				0.00		NM	138.65	83.04
1980s	603.85	57.40	71.22		2.54	0.39				10.87		2.48	180.37	45.36
1990s	615.51	47.31	71.92		4.23	0.38				10.38		9.30	185.29	41.09
2000s	619.67	41.14	73.84		4.18	0.00				10.31		14.00	191.00	38.78

Table 4 (cont): Change in land cover and habitat (ha) by Location.

	Natural vegetation	Agricultural land	Residential area	Industrial area	Passive Recreational area	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
Location 5														
1940s	2302.29	22.14	0.59									13.59	143.28	40.68
1950s	2319.65	19.37	0.82									NM	144.53	27.69
1980s	2329.15	16.96	1.18									3.50	168.66	13.00
1990s	2337.45	14.25	3.16									4.95	176.90	8.19
2000s	2342.24	15.04	3.36									2.53	179.15	8.55
Location 6														
1940s	816.34	109.61	0.00							5.01			163.12	225.47
1950s	838.95	100.24	0.64							4.56			182.72	199.86
1980s	847.34	103.32	14.85							4.70			212.96	147.23
1990s	839.13	119.17	23.69							4.46			215.34	130.24
2000s	869.59	108.36	21.69							4.46			218.98	110.93
Location 7														
1940s	303.97	303.78	0.00										38.45	30.61
1950s	348.29	262.38	0.00										44.98	26.94
1980s	319.30	301.04	7.28										68.26	15.22
1990s	311.22	302.38	16.16										71.12	10.95
2000s	335.52	274.82	15.93										79.91	9.87
Location 8														
1940s	NA	NA	NA		NA				NA				NA	
1950s	NA	NA	NA		NA				NA				NA	
1980s	186.45	160.76	18.10		18.18				2.60				7.43	
1990s	183.23	155.50	15.86		22.60				2.39				8.65	
2000s	183.72	154.89	13.78		24.32				2.52				9.73	

Table 4 (cont): *Change in land cover and habitat (ha) by Location.*

	Natural vegetation	Agricultural land	Residential area	Industrial area	Passive Recreational area	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
Location 9														
1940s	NA	NA	NA						NA					
1950s	NA	NA	NA						NA					
1980s	173.72	207.81	28.60						1.54					
1990s	162.05	214.75	30.11						3.30					
2000s	203.62	172.97	31.04						1.63					
Location 10														
1940s	NA	NA	NA						NA					
1950s	NA	NA	NA						NA					
1980s	173.80	424.36	103.77						3.29					
1990s	179.85	414.78	106.84						3.47					
2000s	224.19	354.38	124.04						0.75					
Location 11														
1940s	53.90	328.98	0.00	0.00			91.99		0.00					
1950s	71.23	295.53	2.46	0.00			98.56		0.00					
1980s	127.74	204.13	37.46	3.45			65.19		1.71					
1990s	142.79	197.80	42.36	3.53			68.31		3.25					
2000s	197.54	175.89	45.09	3.25			28.56		3.91					
Location 12														
1940s	39.44	265.83	15.65	66.13	0.00			23.90						
1950s	31.6	292.2	19.0	60.12	0.00			1.9						
1980s	78.87	71.56	77.27	115.07	47.93			1.04						
1990s	86.96	72.76	80.77	104.80	45.00			1.99						
2000s	114.65	60.66	94.02	85.21	44.66			0.00						

Table 4 (cont): *Change in land cover and habitat (ha) by Location.*

	Natural vegetation	Agricultural land	Residential area	Industrial area	Passive Recreational area	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
Location 13														
1940s	349.04	0.00	0.98		0.00	0.00	15.64	0.00			0.00			
1950s	327.47	0.00	1.52		0.00	0.00	29.34	0.00			0.00			
1980s	329.17	19.53	2.18		6.13	0.48	3.35	0.82			3.60			
1990s	331.79	20.47	2.05		5.27	2.58	1.29	0.71			3.58			
2000s	312.75	34.48	2.13		5.81	0.00	3.82	1.68			3.02			

Table 5. Variation in trajectory of change.

Type of variation	Land cover	Decade	Location
High period	Seagrass	1980s	3
	Agricultural land	1950s	4
	Natural vegetation	1980s	6
	Agricultural land	1990s	9
	Reservoir	1990s	9
	Dry riverbed	1980s	13
Low period	Natural vegetation	1980s	4
	Natural vegetation	1990s	9
	Natural vegetation	1950s	12
Variable	Agricultural land	-	6
	Natural vegetation	-	7
	Agricultural land	-	7
	Industrial area	-	12

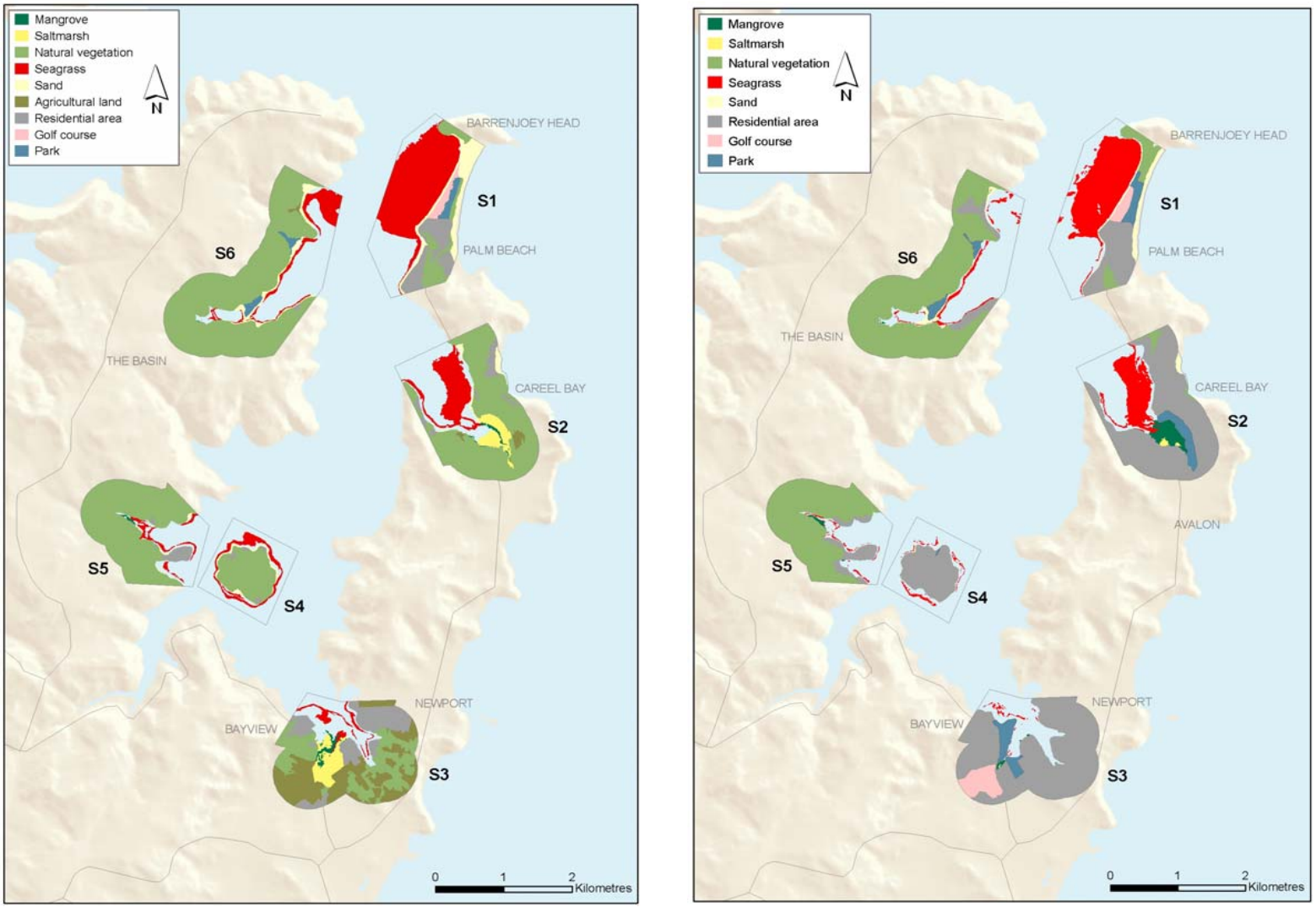

Figure 3. Maps of Location 1 with its six sites for the 1940s (left) and 2000s (right).

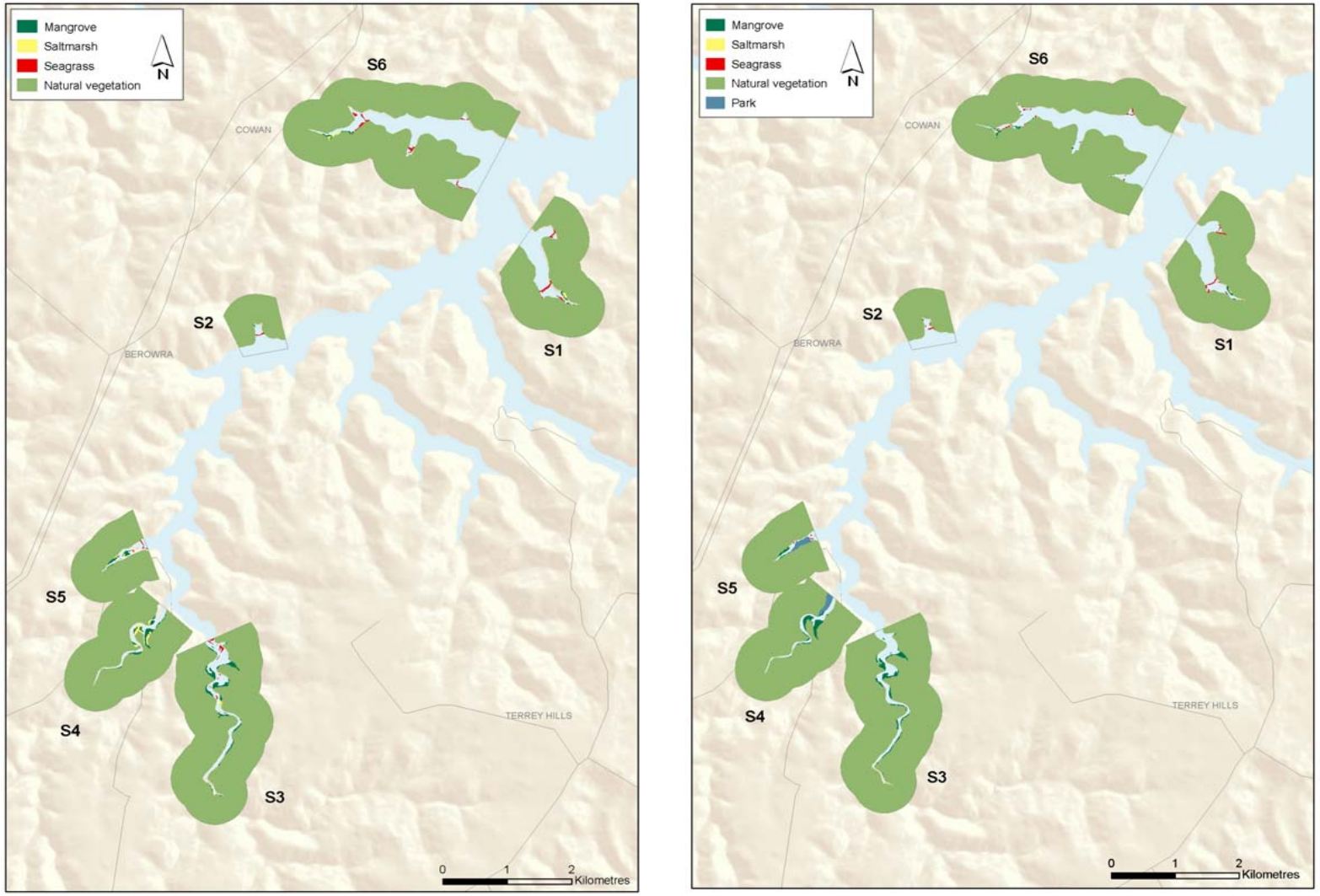

Figure 4. Maps of Location 2 with its six sites for the 1940s (left) and 2000s (right).

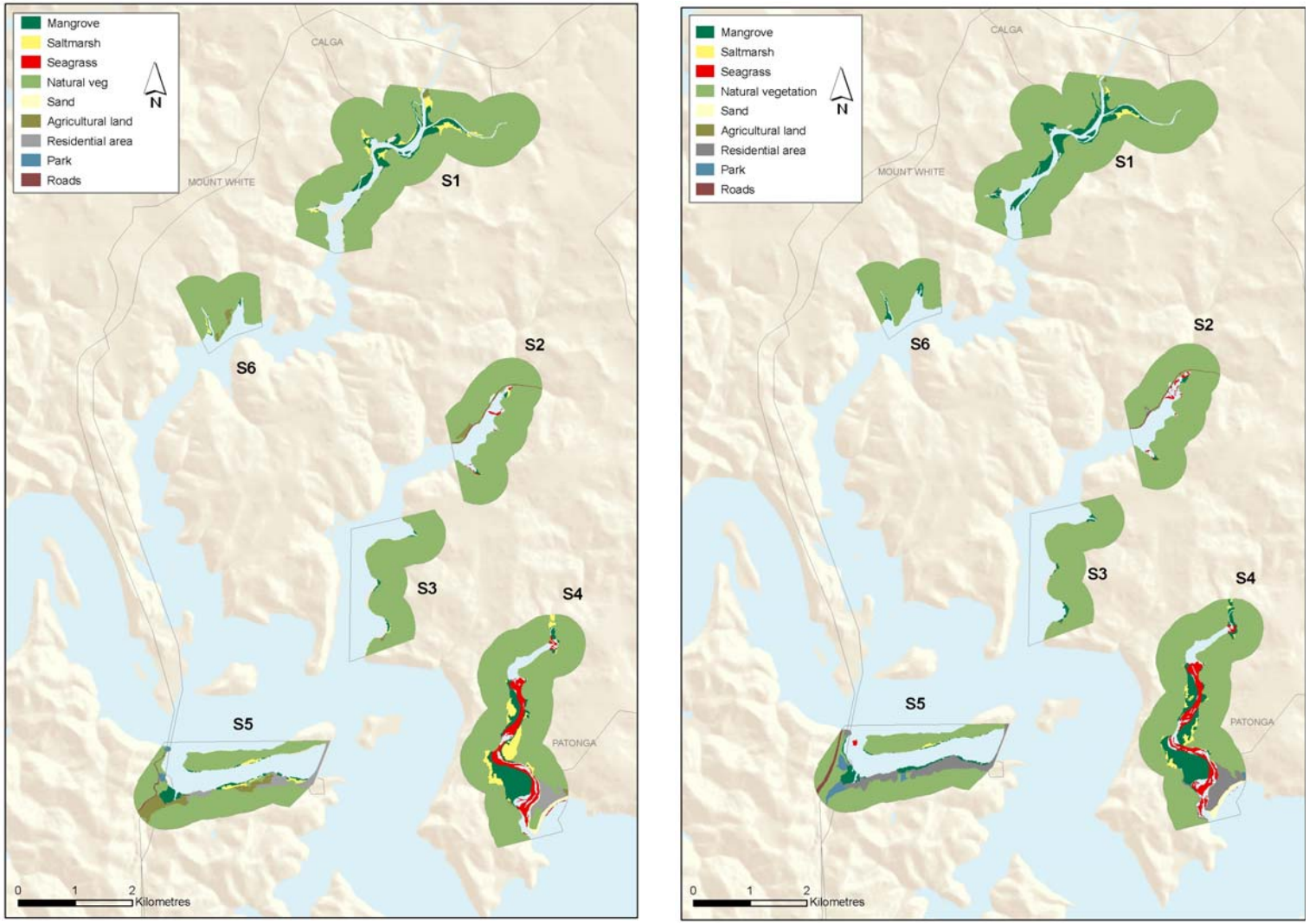

Figure 5. Maps of Location 3 with its six sites for the 1940s (left) and 2000s (right).

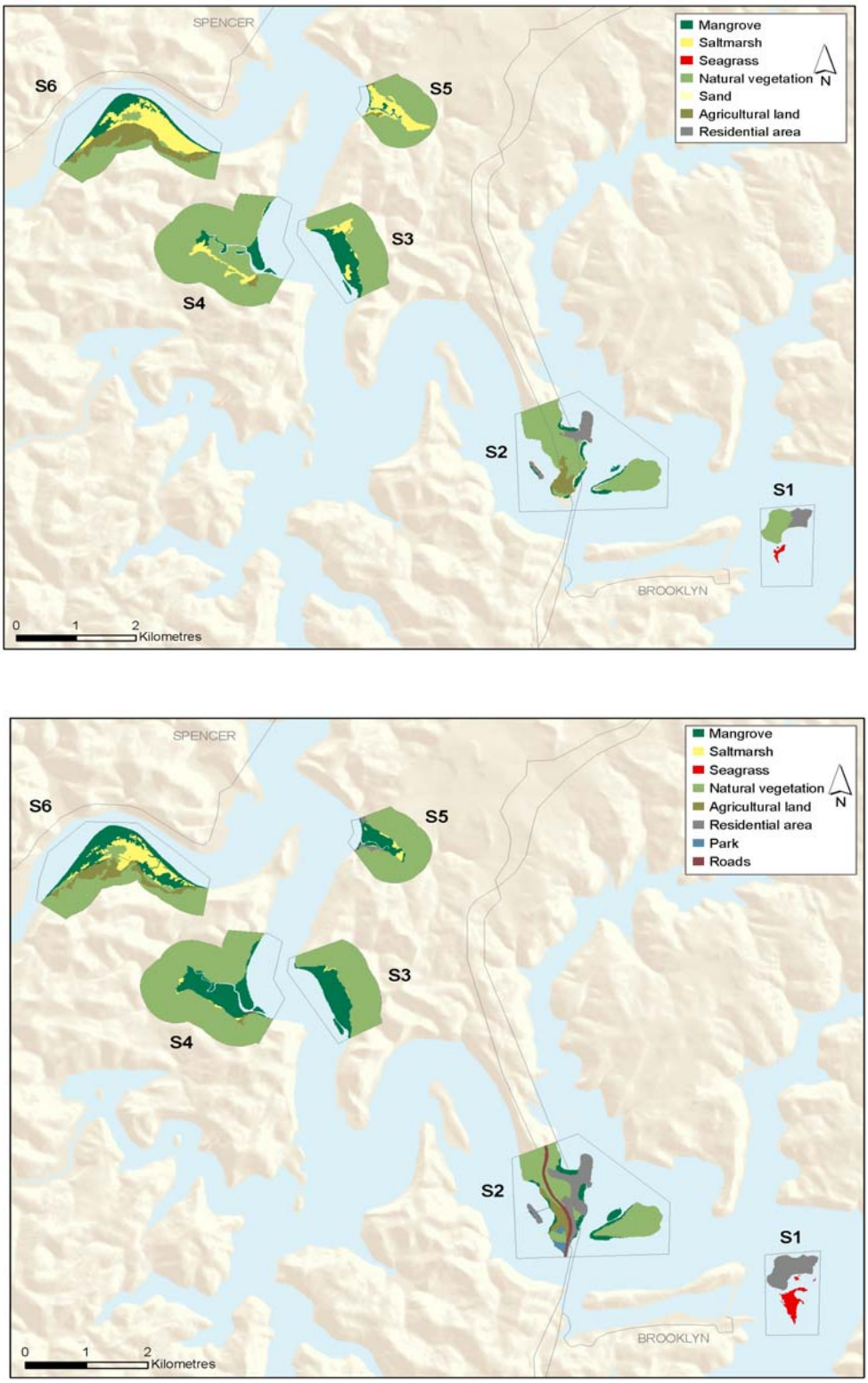

Figure 6. Maps of Location 4 with its six sites for the 1940s (top) and 2000s (bottom).

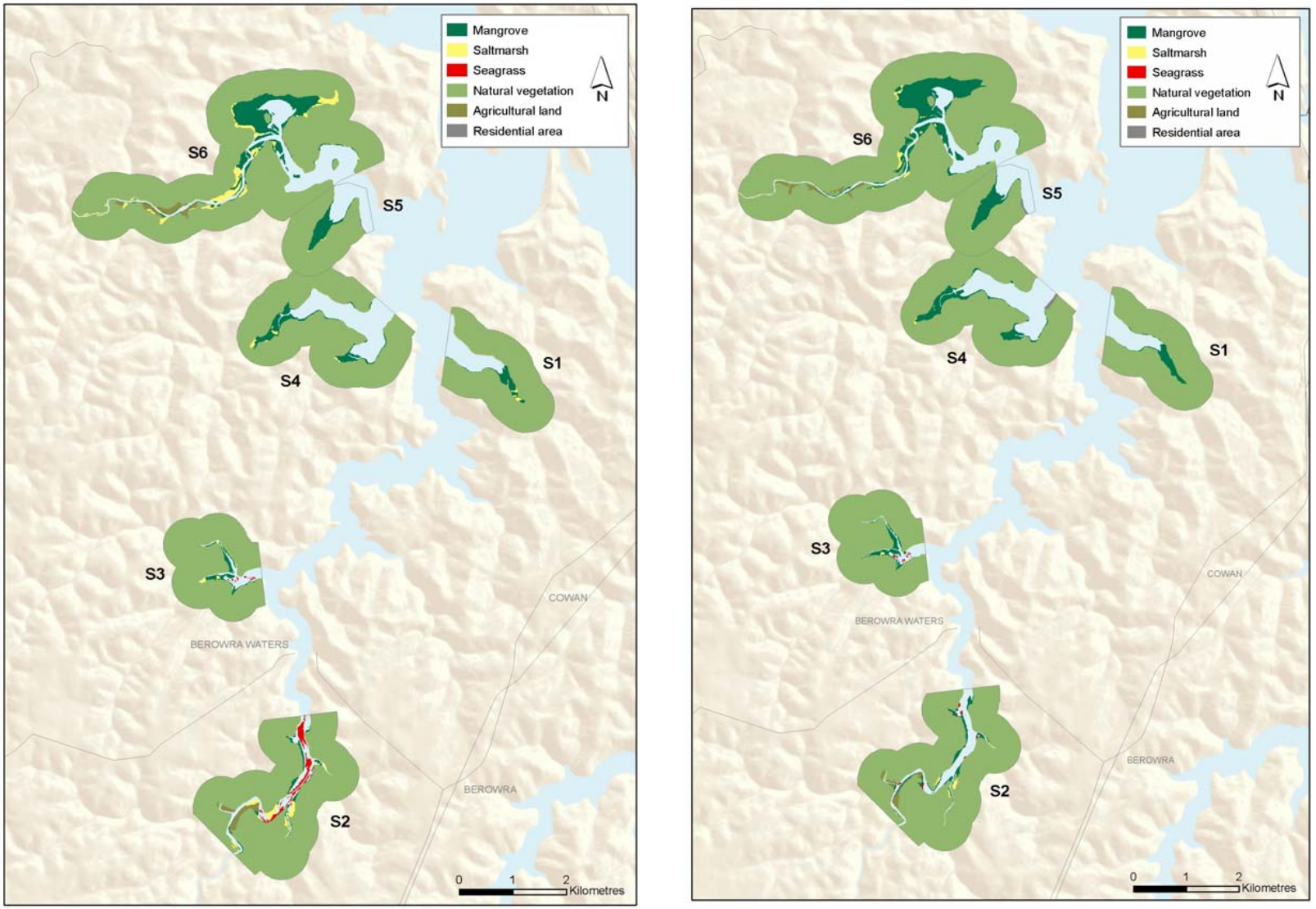

Figure 7. Maps of Location 5 with its six sites for the 1940s (left) and 2000s (right).

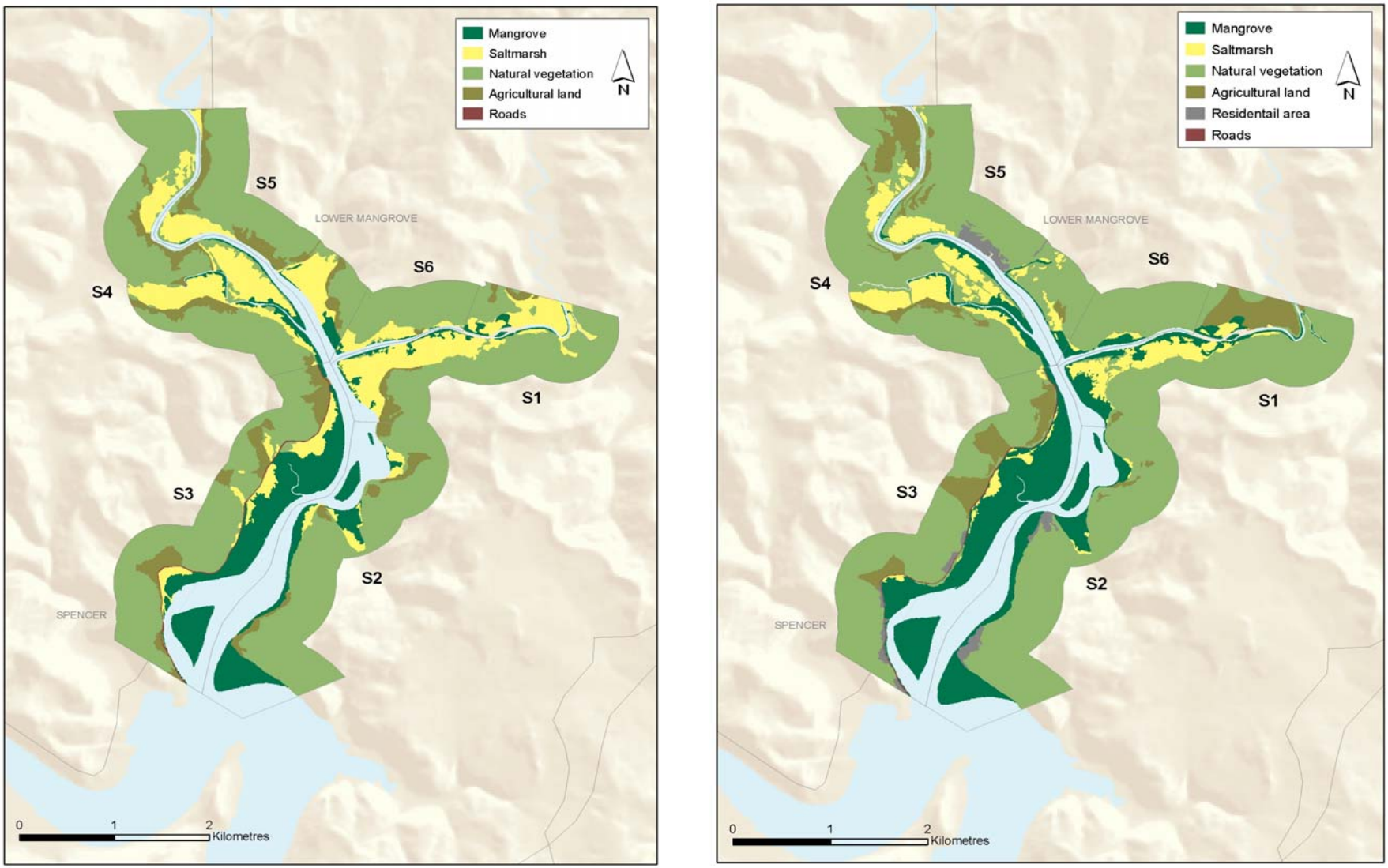

Figure 8. Maps of Location 6 with its six sites for the 1940s (left) and 2000s (right).

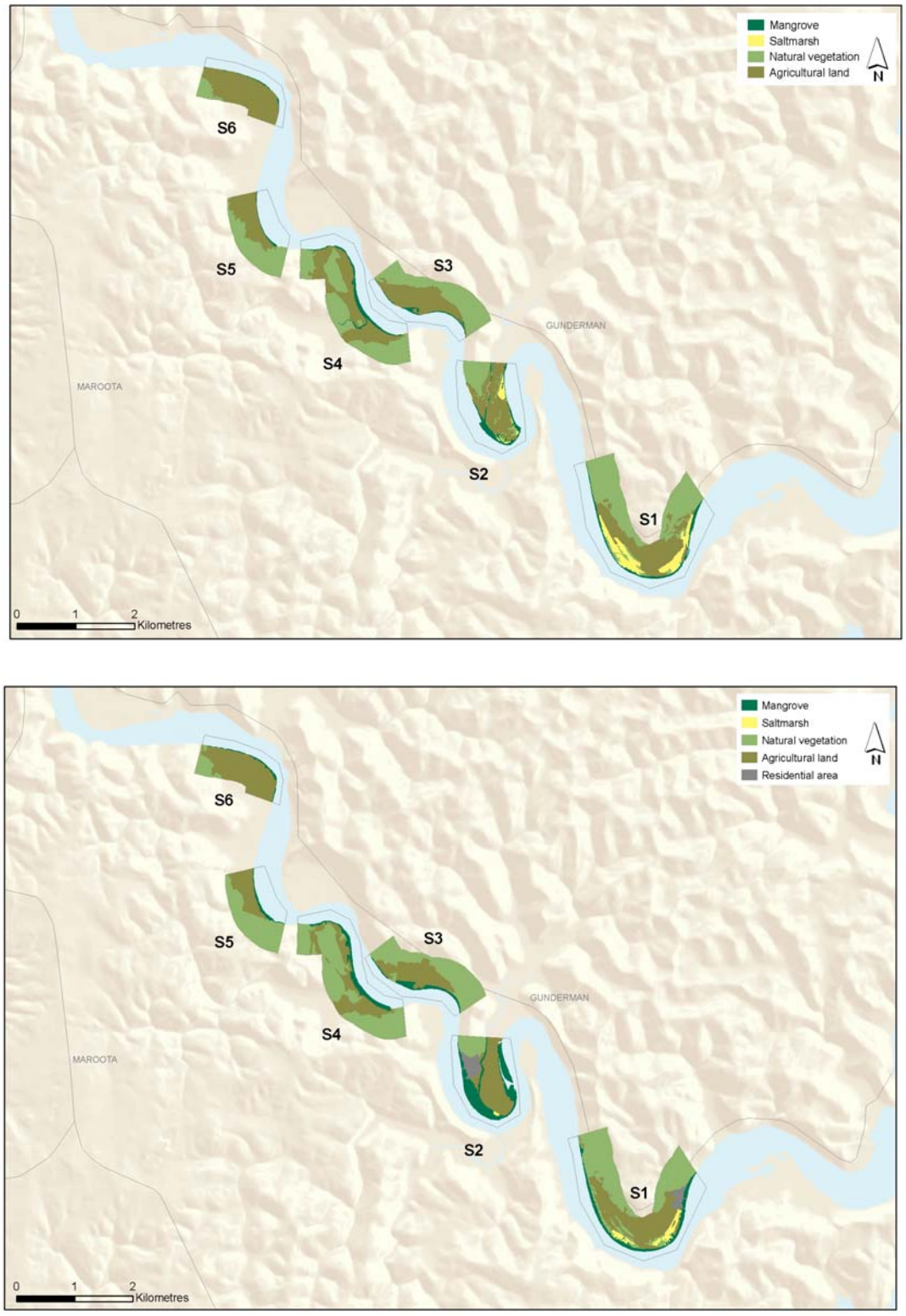

Figure 9. Maps of Location 7 with its six sites for the 1940s (top) and 2000s (bottom).

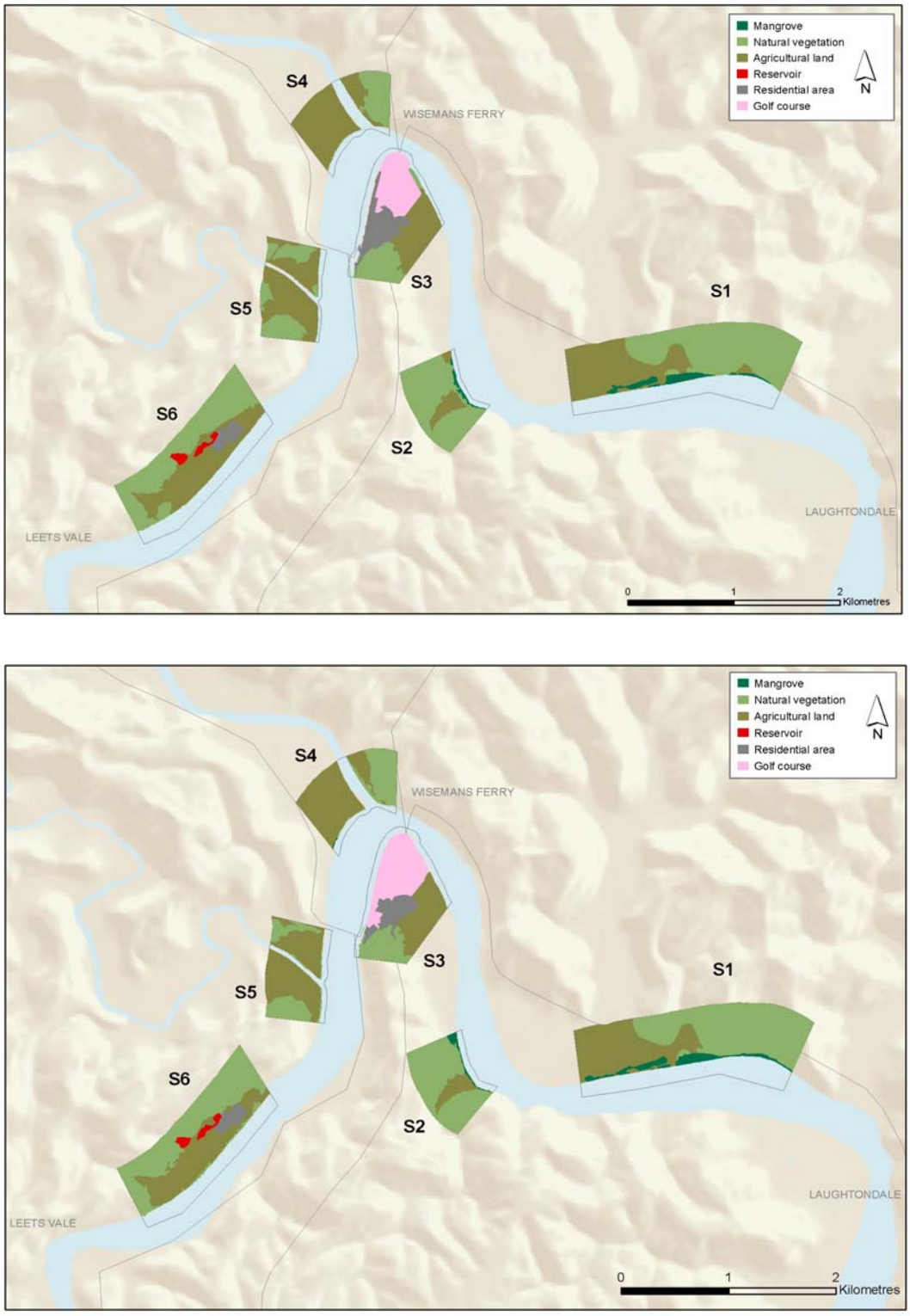

Figure 10. Maps of Location 8 with its six sites for the 1980s (top) and 2000s (bottom).

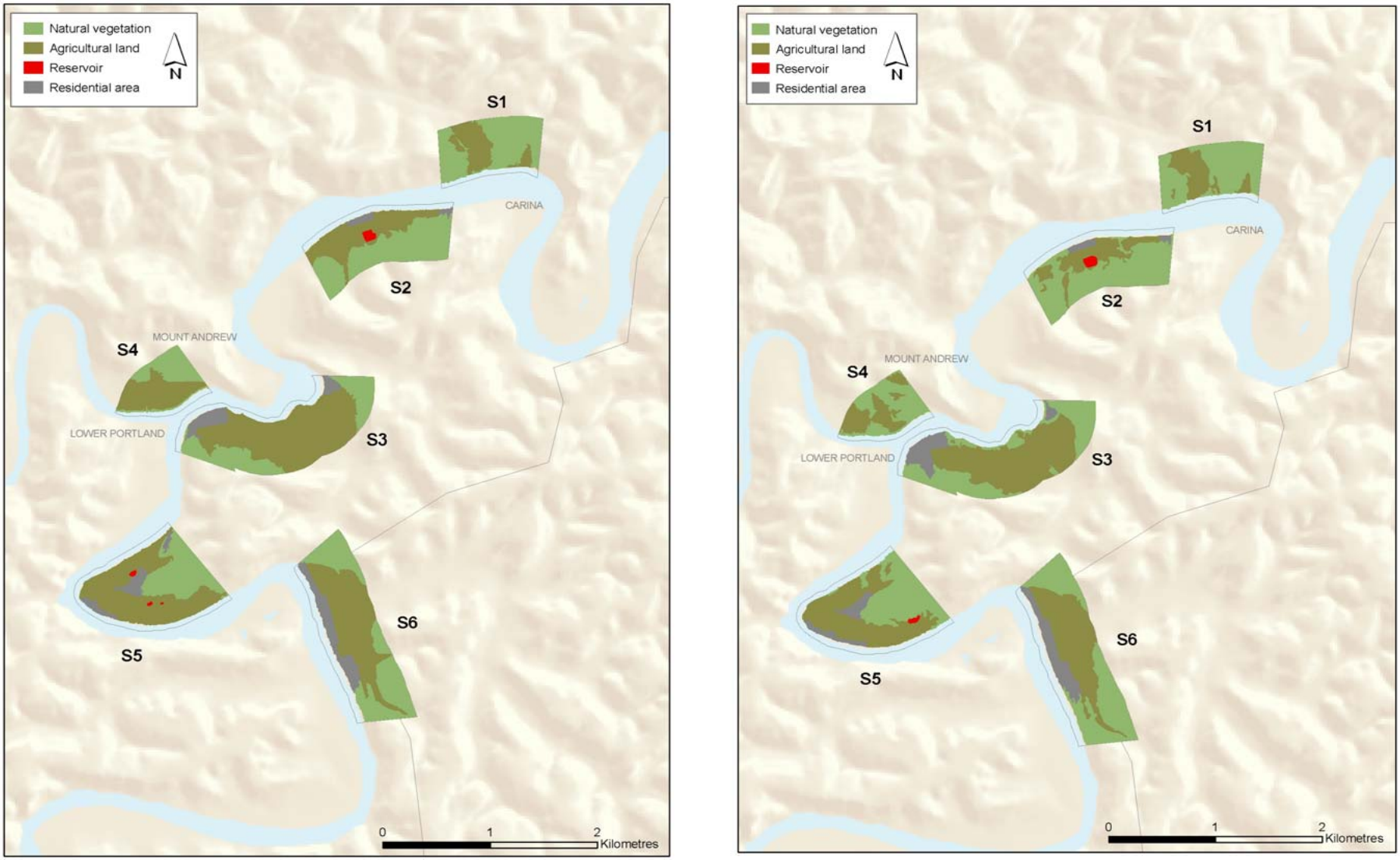

Figure 11. Maps of Location 9 with its six sites for the 1980s (left) and 2000s (right).

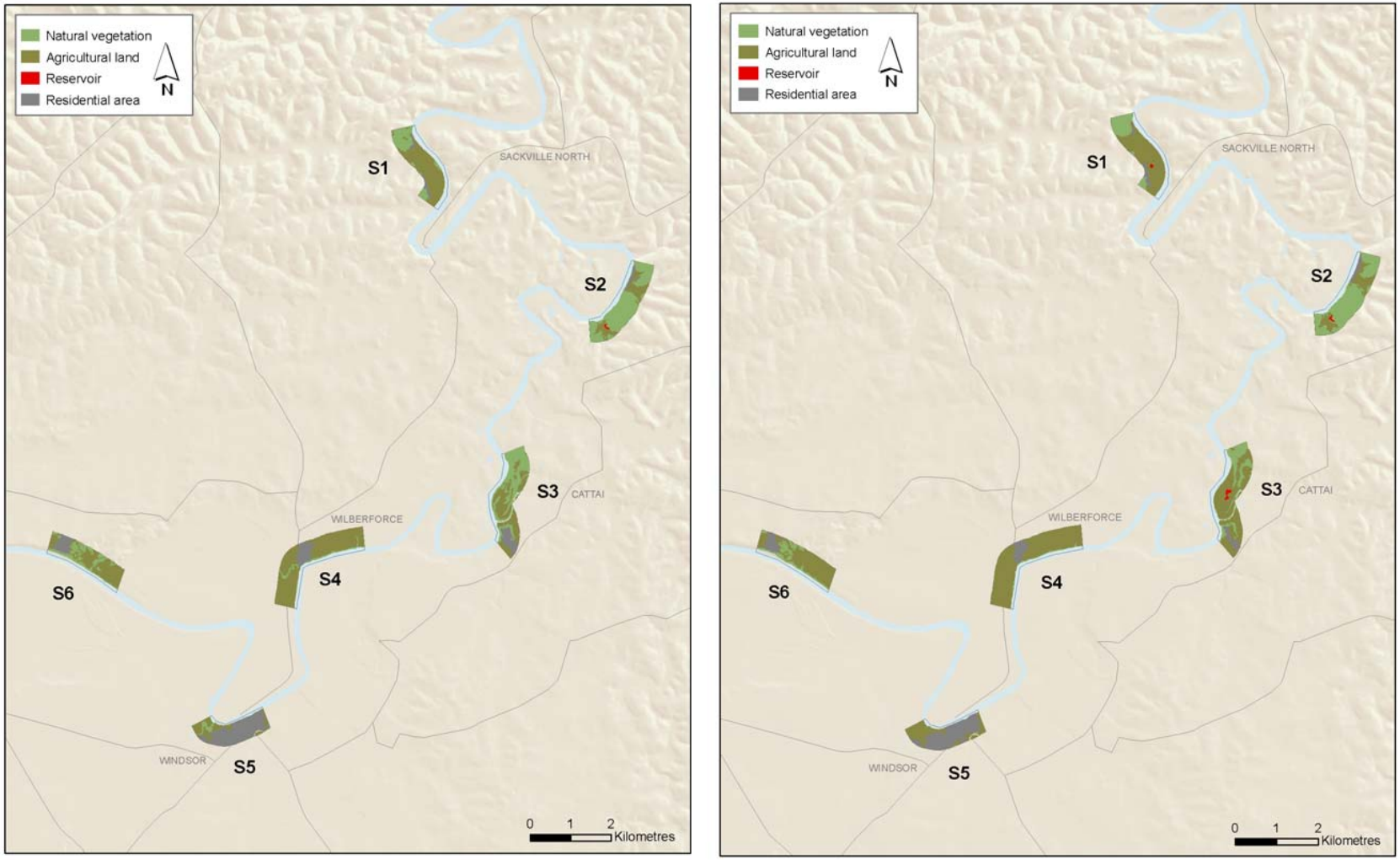

Figure 12. Maps of Location 10 with its six sites for the 1980s (left) and 2000s (right).

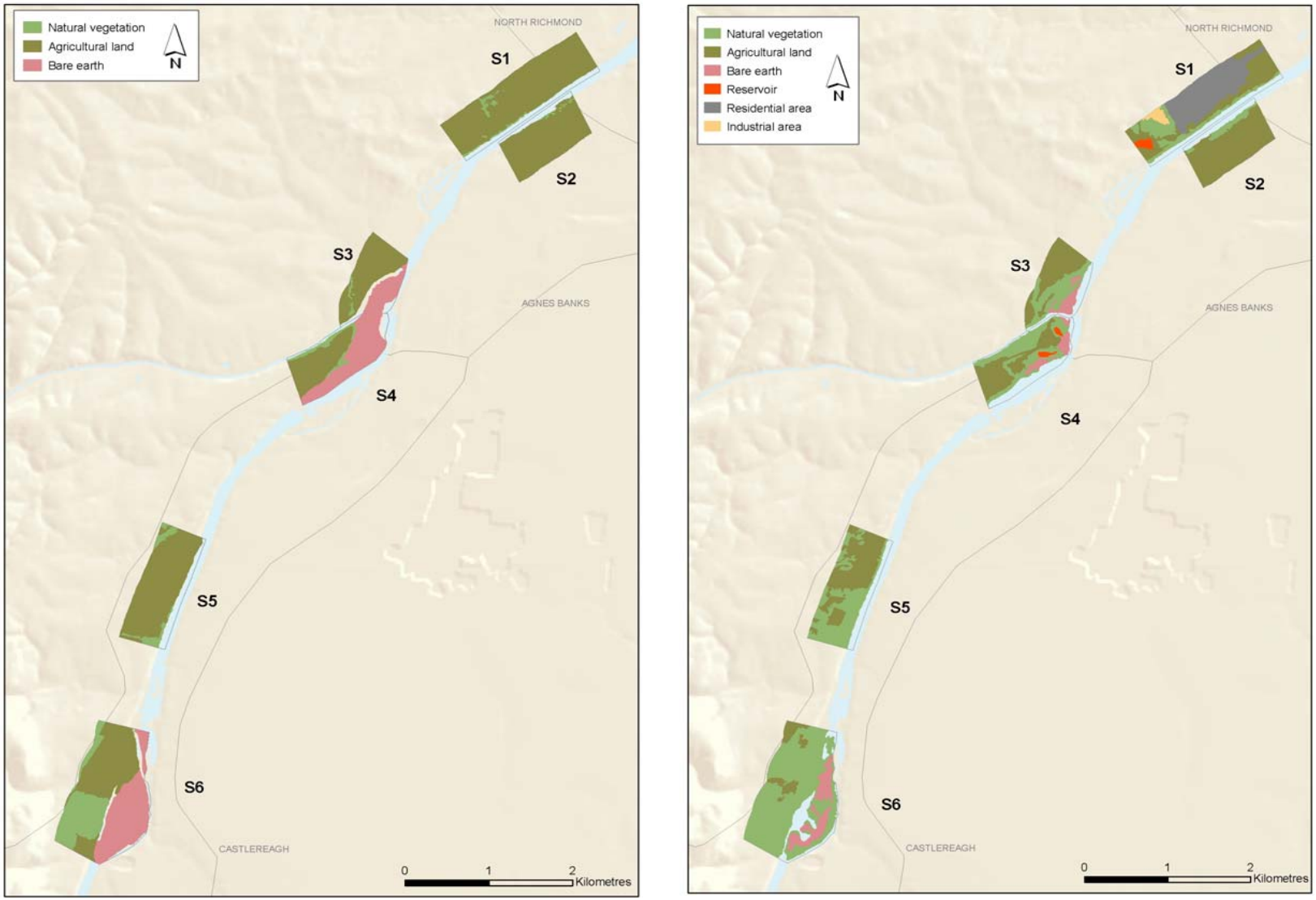

Figure 13. Maps of Location 11 with its six sites for the 1940s (left) and 2000s (right).

Figure 14. **Maps** of Location 12 with its six sites for the 1940s (left) and 2000s (right).

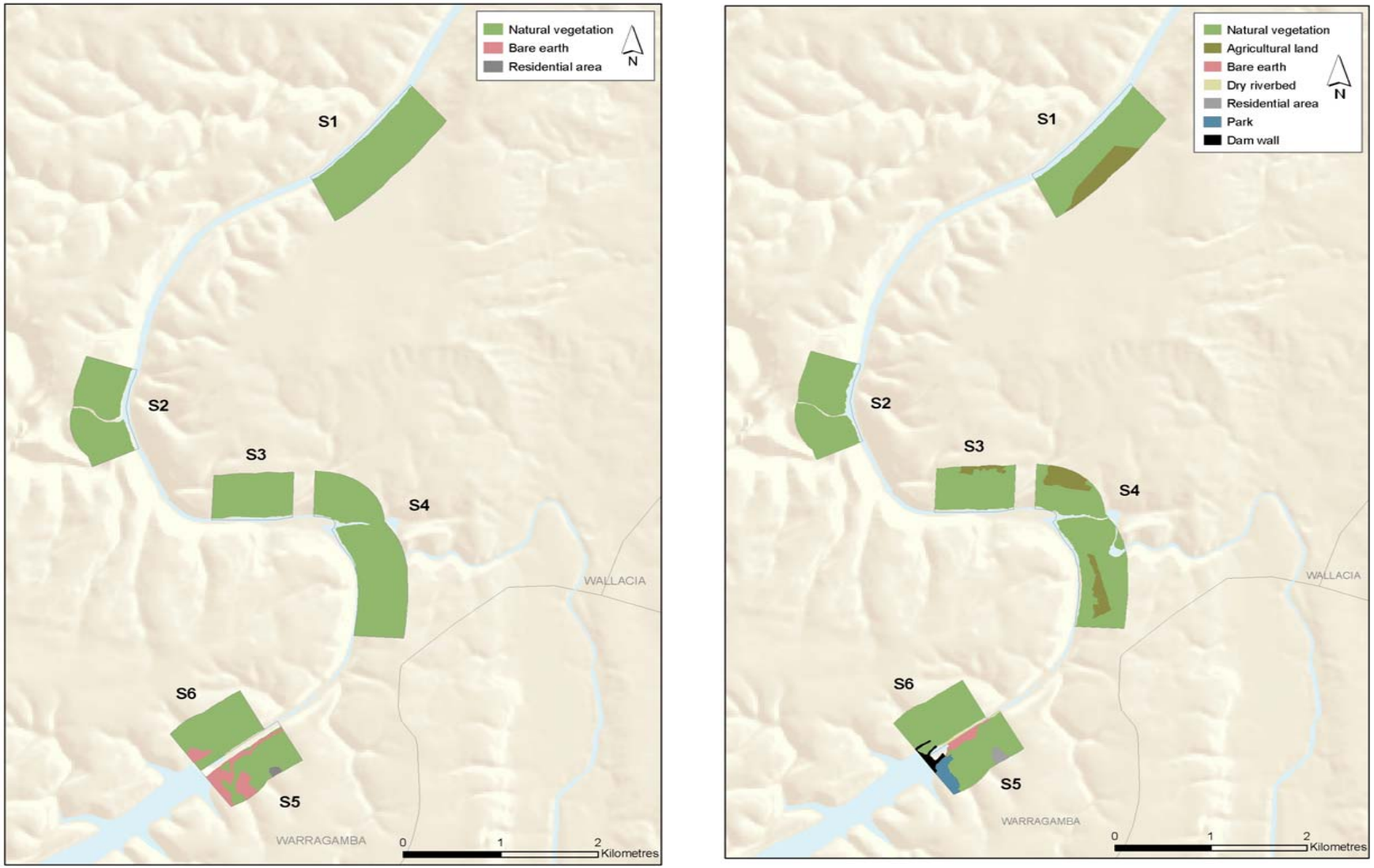

Figure 15. Maps of Location 13 with its six sites for the 1940s (left) and 2000s (right).

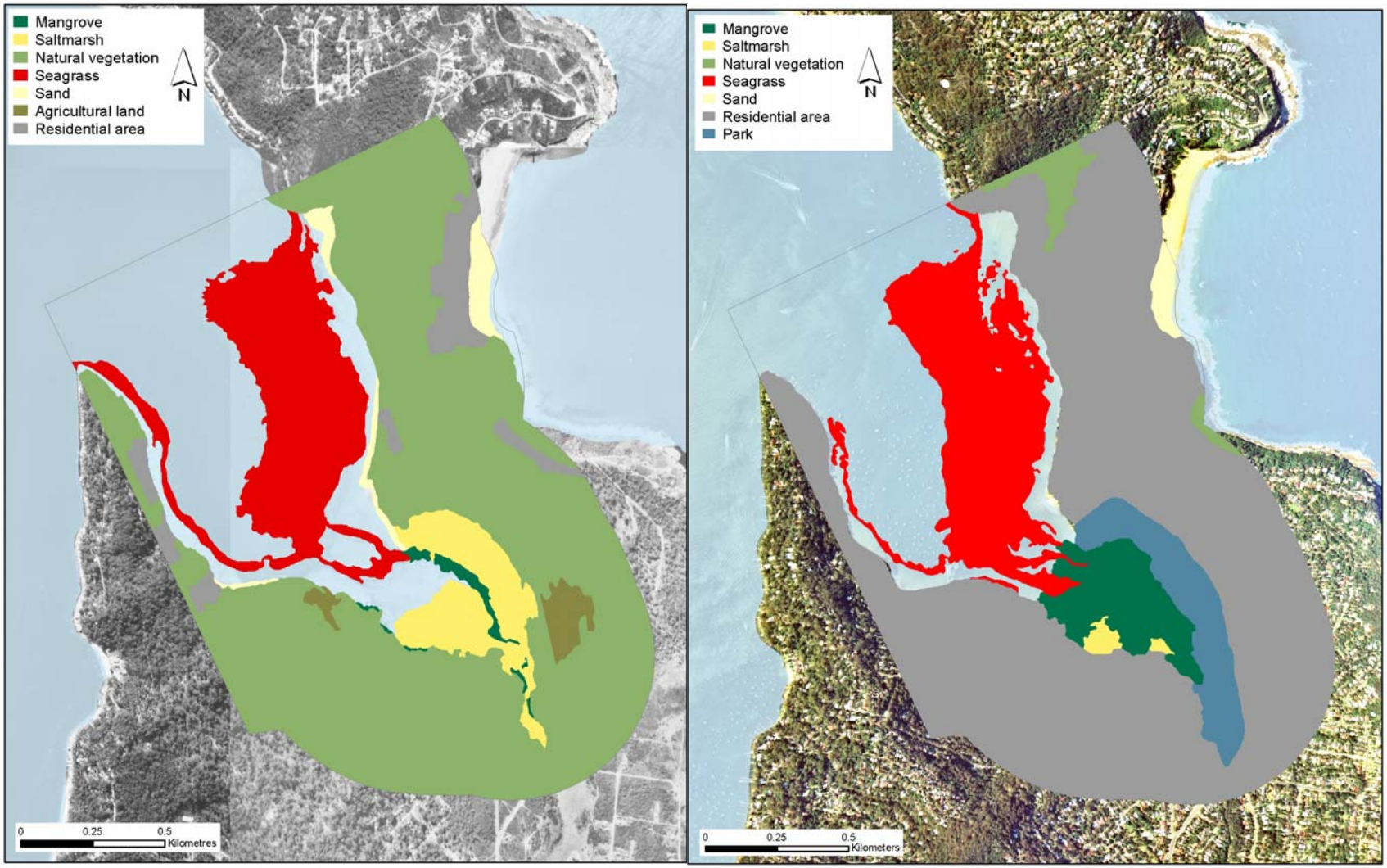

Figure 16. Maps of Site 2 at Location 1 for the 1940s (left) and 2000s (right).

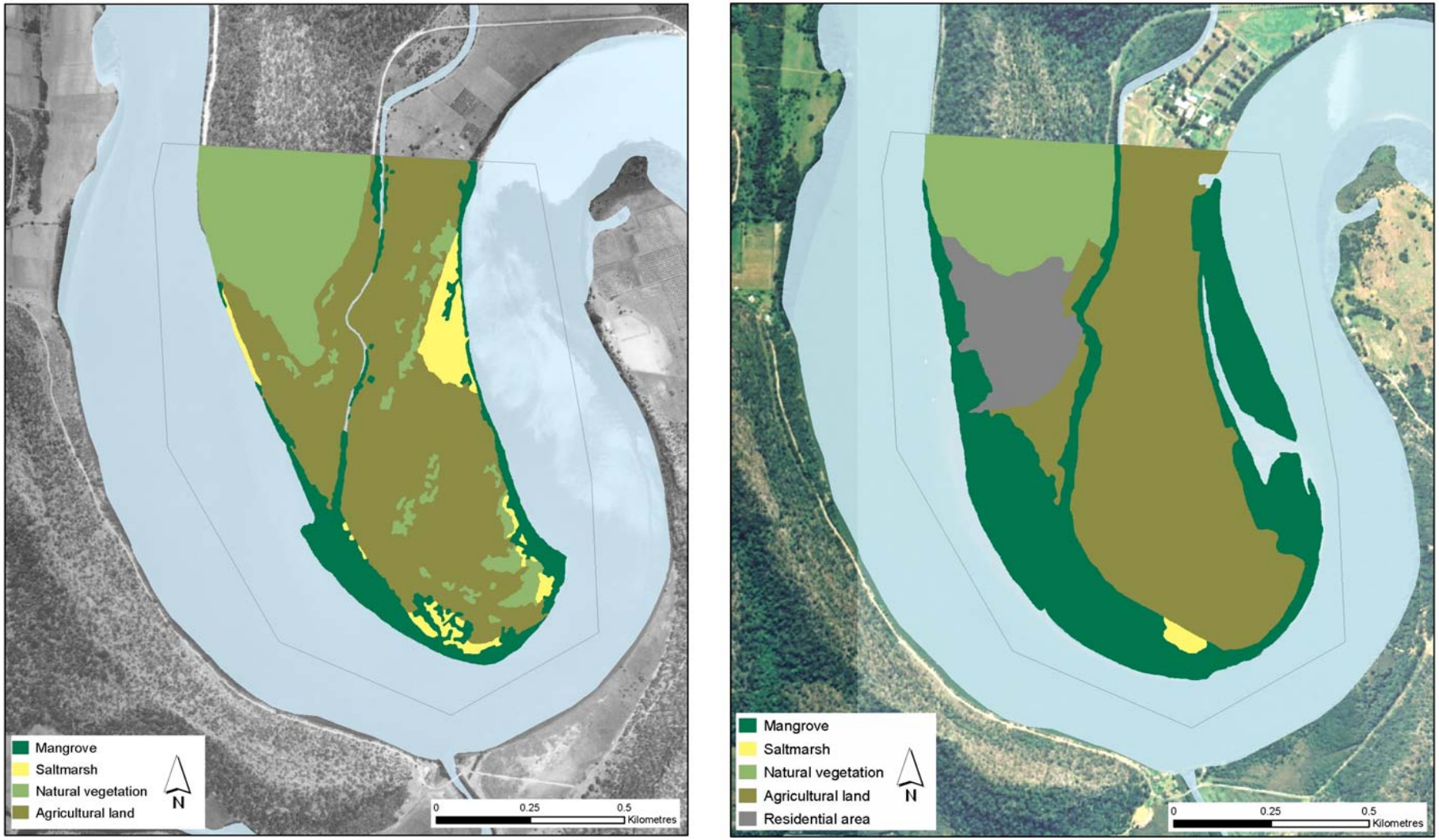

Figure 17. Maps of Site 2 at Location 7 for the 1940s (left) and 2000s (right).

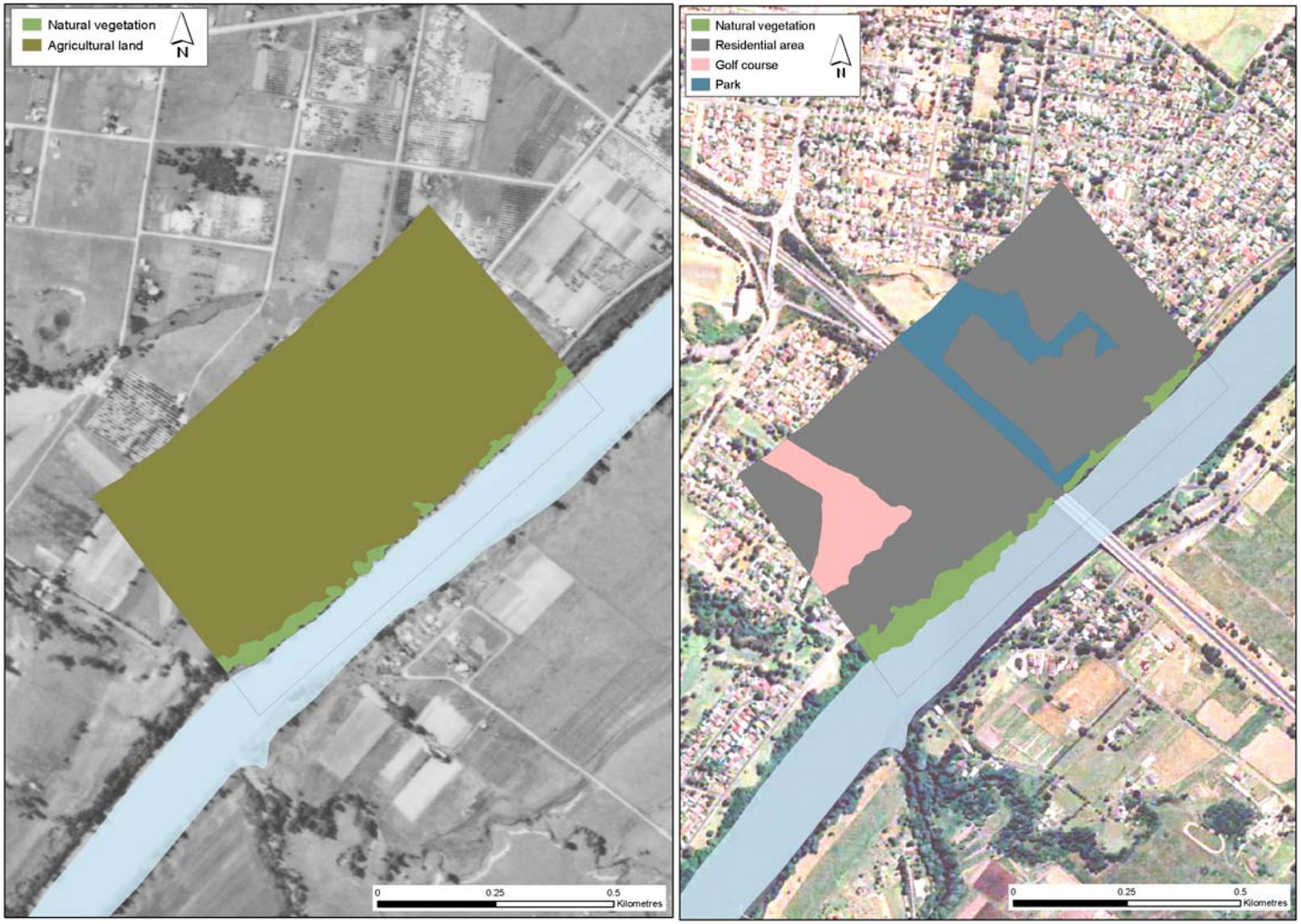

Figure 18. Maps of Site 6 at Location 12 for the 1940s (left) and 2000s (right).

3.4. Weeds

Due to the elevation of the aircraft, scale of photography and the turbidity of the water in the upstream section of the Hawkesbury Nepean River, none of the freshwater weed species mentioned in the Introduction were mappable from current or historical aerial photos, but some were identified during field checks. These included *Egeria*, *Salvinia* and Willow. *Egeria*, even though in recent years it has occluded the river between Colo River (Location 9) and Windsor (Location 10), was not seen in any of the analysed photos. Nor were *Cyperus*, any of the species of Horsetail, *Lagarosiphon*, or Subterranean Cape Sedge located.

The distribution of *Caulerpa* is mainly off Palm Beach, but as well within Careel Bay, and along the eastern shoreline of Scotland Island. Recent observations suggest small patches occur along scattered parts of the western shore of Pittwater from the Basin to Church Point, and off Patonga Beach (T. Glasby, pers. comm., 2007). Sparse beds were encountered in Careel Bay during the field validation conducted for this study. NSW DPI is monitoring its extent (T. Glasby, pers. comm., 2006).

4. DISCUSSION

One of the aims of this project was to assess and interpret changes key aquatic habitats of the Hawkesbury Nepean River. Within the estuary, and on the basis that seagrass, mangrove, and saltmarsh integrate the effect of pollutant and nutrient inputs derived elsewhere in the catchment, any changes in type or extent of cover, can give insight into a range of land use issues. In a similar way, the historical distribution of the freshwater submerged plant *Vallisneria* could be used to assess change in the freshwater parts of the river system. Unfortunately, until recently, the distribution of the latter has not been mapped. It would appear that the cover of *Vallisneria* has been reduced over the past decade by expansion of introduced species such as *Egeria densa* and *Elodea canadensis* (Thiebaud *et al*. in prep.), but this could not be substantiated from the analysis of aerial photos used for this project. It is important that in future the cover of all submerged aquatic plants in the Hawkesbury Nepean river system be monitored.

4.1. Technical implications

Table 1a and 1b show change in the extent of cover of seagrass, mangrove and saltmarsh for the whole of the Hawkesbury River and Pittwater, respectively, over the past 20 years. It is necessary to note that over this time there has been an advancement of mapping technology with which to examine aerial photographs. West *et al*. (1985) used the *camera lucida* technique (a series of optics), whereas West, G. (unpublished a, b) and this study used GIS facilities, albeit with slight modifications. When the results from the two former techniques are compared, the Hawkesbury River showed a small loss of seagrass and mangrove but a curiously large increase in saltmarsh. Either the saltmarsh expanded extensively, or more likely, the increase was an artefact arising from an underestimation of cover by the earlier technique.

Underestimation of cover arises from innate limitations in characterising the environment from a distance (remote sensing), but additional complications may arise from the quality of the photographs used. West *et al*. (1985) were reliant on black and white photographs at scales ranging from 1: 16,000 to 1: 40 000, and spatial resolution for the more detailed of these photos was of the order of 2m. Better quality photos became available from the early 1980s, when colour was introduced into the photographic process for photos taken of NSW. The colour photos taken in 1997 were at the scale of 1: 16 000 and therefore a better assessment of small scale features was possible. This, coupled with the capabilities of GIS to magnify the image, is thought to account for the apparent large increase in saltmarsh seen in Table 1a.

Saltmarsh is notoriously difficult to map accurately with remote sensing techniques. Kelleway *et al*. (2007) report a substantially greater amount of saltmarsh in the Parramatta River/Sydney Harbour from pedestrian survey than with aerial photographic interpretation. Seventy percent of the patches that they found in that study were less than 100 m^2 in area, and could not be located in aerial photos even when magnified. Where saltmarsh occurs in larger patches it is sometimes hidden from view in aerial photos as it is under mangrove or terrestrial vegetation. Where saltmarsh intermingles with mangroves there may be a need for special mapping protocols such as spectral analysis to delimit one group of plants from another.

To assess this apparent large gain in saltmarsh seen in the Hawkesbury River from the late 1970s to the present, we undertook further examination of the situation at Location 7 (Table 6). The cover of saltmarsh at Location 7 was consistent for the two most recent analyses, but there were two historical anomalies. Firstly, there was an inconsistency in analyses of photos taken in 1997. As well, there appeared to be a large increase from the photos of 1977 – 78 to the analyses of the 1997 photos.

The first anomaly is explained in terms of a difference in GIS methodologies used in this study and used by West, G. (unpublished a) in which a raster-based supervised classification technique was used for the latter, and direct vector-based on-screen digitising technique was used by us. The vector technique appears to offer a greater sensitivity to the determination of saltmarsh.

The small amount of saltmarsh derived from the photos taken in 1977 – 78 needs to be considered in terms of relatively poor scale (1: 16 000 to 1: 40 000), type (black and white) and technique used at that time (*camera lucida*). It may be appropriate to reanalyse the historical photos of the Hawkesbury River used by West *et al*. (1985) to determine if a greater cover of saltmarsh was present at that time than was recorded.

Table 6. Comparison between West *et al*. (1985), West (unpublished a) and this study of the cover of saltmarsh, mangrove and seagrass for Location 7. Data from the 1997 and 2000 aerial photographs were summed across the six sites at each location.

	West *et al*. (1985)	**West (unpub. a)**	**This study 1990s**	**This study 2000s**
Aerial photo year	1977 – 78	1997	1997	2000
Saltmarsh (ha)	2.51	4.94	10.95	9.87
Mangrove (ha)	59.9	74.03	71.12	79.91
Seagrass (ha)	nil	nil	nil	nil

The cover of mangrove at Location 7 shows a consistent story in relation to assessments conducted in recent years (Table 6). There was a modest increase at this site relative to 1977 – 78, and, because mangroves are more accurately mapped from aerial photos, this increase is assumed to represent a real change. Expansion of mangrove is a phenomenon seen across the whole of southeast Australia (Saintilan and Williams 1999, 2000).

4.2. Management implications

None of the species of aquatic weed identified in this project could be mapped from aerial photos, but some were located during field checks. A species that was encountered in the field was the alga Caulerpa, which is the subject of a large-scale research and monitoring project being carried out by NSW DPI at estuaries along the central and southern coast.

One of the first sites in NSW at which *Caulerpa* was located was Careel Bay in Pittwater (Creese *et al*. 2004). Early results from field experiments (T. Glasby, pers. comm., 2006) suggest seagrass and *Caulerpa* can coexist, unless the latter takes hold in an area of sparse seagrass cover, particularly of *Zostera* spp. A number of methods of eradication have been attempted at Careel Bay and elsewhere: the application of Hessian bags, rubber mats and salt were assessed. The large-scale dumping of salt was found to be the most cost effective technique, at least in the short term (Creese *et al*. 2004).

The other main aquatic weeds occur upstream as well as downstream of Warragamba Dam. Their presence was the subject of recent investigations by the NSW Aquatic Weed Task Force (Hawkesbury Nepean Aquatic Weeds Scientific Committee 2006). *Egeria*, while not on the Commonwealth list of noxious weeds, was the top priority for examination by the committee. *Egeria densa* was subsequently declared a noxious weed under the NSW Weed Control Order 21 in February 2001.

Alligator weed was recognised as a weed of national significance after its apparent arrival in the Hunter River in the 1940s (CRC for Australian Weed Management 2003a). *Salvinia*, first recorded as a weed near Sydney in 1952, is also recognised as a weed of national significance due to its economic and environmental impacts (CRC for Australian Weed Management 2003b). Because these species have rarely been eradicated from waterbodies once they have taken hold, the highest priority for managing them properly is an effective system of early detection and eradication before an infestation becomes established.

Of the terrestrial weeds, two of the most important are Spiky rush and Willow. The former appears to grow at the highest of tidal levels in the more upstream portions of estuaries and is recognised as a major invader, taking over the habitat of the indigenous Salt rush (*Juncus krausii*). At some locations in NSW, notably the lower Hunter River (P. Svoboda, pers. comm. 2006), and Sydney Olympic Park (Paul and Young 2006), major investments have been made in the removal of the Spiky rush Once removed, follow-up is needed due to the large seed bank dropped in the sediment by this species. Willow trees, of which there are several species, are recognised as a weeds of national significance (CRC for Australian Weed Management 2003c), and it is understood that there are clearance projects in place in the catchment of the Hawkesbury River.

At the catchment scale, and specifically in terms of land use changes that have occurred in the study zone over recent decades, Table 3 shows that the cover of natural vegetation has varied from one location to the next, while there has been an overall decrease in agricultural land and increase in residential land. These observations can focus the needs of managers to further examine the degree of change along whole stretches of the river. For example, because estuarine macrophytes are so important to the sustainable function of estuaries, and because there appears to be a negative correlation between change in land use and the variation in cover of seagrass and saltmarsh (Table 3), there is a need to further quantify the gain/loss in all subcatchments. This report provides the data by which graphical summaries of these changes can be made but it was beyond the scope of the project to examine site-specific details. This report does not set out cause and effect relationships, but provides a series of observations from which correlative inferences may be drawn.

There appears to be a positive correlation between change in landuse and increases in cover of mangrove, and this relationship needs to be explored. The fact that change has occurred at different intensity and tempo within the lower portion of the catchment offers potentially significant insights into what cause and effect relationships might exist. If, for example, the history of land use for the whole of the subcatchment of Berowra Creek or Cowan Creek were to be assessed, a far better understanding of the dynamics of the cover of the estuarine macrophytes could be obtained than by analysing somewhat arbitrarily chosen sites. Such an investigation would document the removal of natural vegetation and associated change in general runoff characteristics, the installation of stormwater facilities and associated change in runoff at specific discharge sites, the history of dredging and reclamation, and the history of erosive events such as floods and storms.

Other relevant events occurring in subcatchments would include the installation of barriers such as dams, floodgates, culverts, bridges and fords. These structures are well recognised as modifiers to tidal flow, in turn having a potential impact on the distribution of vegetation such as seagrass, mangrove and saltmarsh (Williams and Watford 1996). Such studies would set the stage for investigations into stormwater treatment and subsequent stormwater management policy. While it is generally agreed that stormwater discharge can have a negative impact on seagrass in terms of erosion and nutrient enhancement (the latter leading to epiphytic overgrowth and impairment of photosynthesis), there have been few studies to actually document what happens when modifications to discharge occur, either in terms of increasing the volume of discharge due to subdivision or other change of land use, or controlling the quality of discharge via the retrofitting

of mini-wetlands. These studies would be manipulative in nature, and be resourced to include observations made before and after change. Appropriate reference sites would need to be included within the study design.

Another outcome of this project, based in part on other studies and observations, is a conceptual model of the distribution of aquatic habitats of the Hawkesbury River. The model is based on the interplay of fresh and tidal waters and the interaction of these forces naturally and following human modification. The model is predicated on the fact that salinity is a major determinant of the distribution of estuarine species. Table 7 is a representation of physico-biological characteristics and their spatial occurrence in relation to the portion of the Hawkesbury River studied. It is colour-coded to assist in differentiating the presence of freshwater features from saltwater features, and the extent of tidal influence is also indicated. The point at which the freshwater features are differentiated from the saltwater features is between Windsor (L9) and the Colo River (Location 10). Three points need to be made:

1. The balance point is determined in large measure by the ability of the tide to penetrate the system. The contorted nature of the lower part of the channel of the Hawkesbury River presumably has a large impact on the extent of tidal penetration.

2. The balance point is a naturally dynamic feature. It will migrate up and downstream depending on rainfall conditions as well as sealevel. The latter stabilised at its present position about 6,000 years ago from a low point during the last glacial era. (However, there is evidence that sealevel was about one half metre higher 3,000 years ago and has since settled back to its present position, Baker and Haworth 2000). Depending on the height of the ocean, the biological characteristics shown in Table 7 will migrate upstream or down from their present position.

3. The balance point will vary in relation to the manipulation of water flow within the catchment. In the Hawkesbury River this includes those manipulations that harvest water for human and agricultural use, the piping of water into the catchment from outside sources, and the concentration of discharge at new locations due to reticulation and treatment of effluent. Manipulation of water flow in these ways will also have an effect in relation to nutrient input, dilution capacity and flushing capacity.

At the very least over the next decades, given the predicted increase in variation in short term rainfall associated with the El Nino Southern Oscillation, the distribution of the biological features at Location 9 and Location 10 should be monitored. Local government authorities as well as state government agencies have responsibility for the management of the aquatic resources of the Hawkesbury River, but because of differences in distribution of resources and local priorities it is appropriate that a regional scale management approach be implemented.

5. CONCLUSIONS

- It is possible to track changes in land use through time for the lower portion of the Hawkesbury Nepean River with GIS.
- It is not possible to track the cover of submerged freshwater plant *Vallisneria gigantea* due to the relatively small size of these beds.
- At all/almost all of the 13 Locations, there have been substantial modifications to terrestrial land use. Urban area has increased, as has the area of parkland and golf course.
- At some Locations there have been large losses of agricultural land.
- Natural vegetation has shown a variable pattern, with stable, increase or decrease in area across the 13 Locations.
- Seagrass has decreased in cover over the past 60 years in the five estuarine locations investigated.
- Mangrove has increased in cover at the eight Locations in which it is located.
- Saltmarsh has decreased in cover at the seven Locations at which it is located.

Table 7. Physico-biological characteristics of the Hawkesbury River downstream of Warragamba Dam, 2005.

Common name	Taxonomic name	Location code	L13	L12	L11	L10	L9	L8	L7	L6	L5	L4	L3	L2	L1
		Location name	Warragamba	Penrith	Grose River	Windsor	Colo River	Wisemans Ferry	Gunderman	Mangrove Creek	Berowra Creek	Main Channel A	Main Channel B	Cowan Creek	Pittwater
		Towns		Emu Plains	Castlereagh Yarramundi Bridge North Richmond	Richmond Wilberforce Cattai Sackville	Lower Portland	Wisemans Ferry							Palm Beach Newport Mona Vale
		Reach				Freemans Argyle Windsor Wilberforce York Canning Clarence Swallow Rock Upper Crescent Lower Crescent Portland Kent Cumberland	Cambridge Sussex Gloucester Liverpool	Bathurst Trollope One Tree	One Tree Foul Weather Sentry Box Haycock			Haycock			

Table 7 (continued) *Physico-biological characteristics of the Hawkesbury River downstream of Warragamba Dam, 2005.*

Common name	Taxonomic name	Location code	L13	L12	L11	L10	L9	L8	L7	L6	L5	L4	L3	L2	L1
Fresh water			Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No
Willow	*Calyx* spp.														
Hydrilla	*Hydrilla*		Yes	Yes	Yes	No	No	No	No	No	No	No	No	No	No
Egeria	*Egeria*		Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No
Elodia	*Elodia*		Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No
Salvinia	*Salvinia modesta*		??	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No
Vallisneria	*Vallisneria gigantica*		Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No
Tidal influence			No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Salt water			No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
River mangrove	*Aegiceras corniculatum*		No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Grey mangrove	*Avicennia marina*		No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Saltmarsh	various spp.		No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Eelgrass	*Zostera* spp.		No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes
Strap weed	*Posidonia australis*		No	No	No	No	No	No	No	No	No	No	No	Yes	Yes
						Tipping	Point								

6. RECOMMENDATIONS

Recommendations to the Hawkesbury Nepean Catchment Management Authority and to relevant local government areas from this study fall into four major headings.

6.1. Research/Monitoring

1. That aerial photos taken in the late 1970s and used by West *et al*. (1985) in their assessment of seagrass, mangrove and saltmarsh of the Hawkesbury River should be reanalysed within a GIS framework to create a more accurate record of cover than was allowed by the technology of that earlier assessment.
2. That aerial photographs for each decade (from the earliest decade available) should be analysed within a GIS framework to compile an historical overview of change of landcover for the whole of the Hawkesbury River. Such an investigation would document the history of erosive events such as floods and storms, removal of natural vegetation and associated change in general runoff characteristics, the installation of stormwater facilities and associated change in runoff at specific discharge sites, the history of dredging and reclamation, and the installation of barriers such as dams, floodgates, culverts, bridges, and fords.
3. That GIS data of cover of seagrass, mangrove and saltmarsh determined from aerial photographs taken in 1997 (G. West, NSW DPI, unpublished a and b) should be compared to the locations and sites used in this project to assess any major changes in cover.
4. As some of the intertidal communities of vegetation (saltmarsh and mangrove) investigated in this study occur on private land, a cadastral map should be overlain on study sites to identify the extent of private ownership. (See also recommendation 7, below.)
5. That regular mapping assessments are required of:
    a. Broad scale change in land use, at five to seven year intervals
    b. Medium scale change in cover of seagrass, mangrove, and saltmarsh at three to five year intervals
    c. Fine scale change in cover of selected aquatic vegetation in the warmer months when they are at their maximum cover. Saltwater species are to include the most upstream mangroves, and the most upstream saltmarsh at yearly intervals. At the same time, assessments should be made of desirable freshwater species *Vallisneria*, and the pest exotic species *Egeria*, *Elodea*, *Salvinia* and others.
6. That condition assessments of saltmarsh should be done based on visual observations following the guidelines of Sainty and Jacobs (1997) or Kessler (2006). Condition rating should consider:
    d. Geomorphic factors, including natural features such as soil type, and unnatural features such as barriers to expansion
    e. Hydrologic factors such as tidal flushing and freshwater inputs
    f. Direct human disturbance such as trampling, vehicle damage, stormwater
    g. Indirect human disturbance such as weeds and litter. Of special importance is invasion of the exotic species *Juncus acutus*
    h. Invasion of saltmarsh by indigenous adjacent species such as mangrove from the intertidal zone and *Phragmites* from the upper slope
    i. General condition such as evidence of plant dieback, presence/absence of fauna.

6.2. Education

7. As in some cases the role of aquatic vegetation is little understood by the community, H-N CMA and LGAs should develop education initiatives to reduce the decline in the cover of

these plants. These initiatives should address the loss of aquatic vegetation from specific landuses relating to the use and maintenance of agricultural land or the expansion of residential land. Further, the concept of "connectivity" between various types of habitats needs to be set out.

8. Efforts by HNCMA to support Community Monitoring of Seagrass Beds should be continued.

9. The role of NSW Maritime in identifying seagrass as a resource to conserved by boaters should be continued.

6.3. Planning

10. As Local Environmental Plans are to be revised in relation to templates issued by NSW Department of Planning, and as these templates have three categories for waterways to be zoned, LGAs use this report to assist in that process.

6.4. Climate Change

11. That it be recognized that climate change is occurring and that preparations be made for it including provision for the elevation of sealevel. More specifically, as sealevel rises, there will be a greater penetration of saltwater into estuaries, i.e., a process of "marinisation" of estuaries will begin.

12. That H-N CMA and LGAs give planning consideration to the influence of climate change on the trends shown within this report. Specifically, amendments to planning instruments (both legislative and voluntary) in the form of imposition of buffer areas, voluntary conservation agreements, and changes to LEP zonings as appropriate are needed.

Recommendations to agencies that undertake mapping of landcover such as was done for this study include:

Research/Monitoring

1. That further studies be undertaken to quantify uncertainty to address issues of confidence in methodologies used, in trends determined, and the adequacy of the proposed interactions and relationships within conceptual models generated.
2. That recognition be given in mapping and monitoring studies to the fact that "marinisation" of NSW estuaries is underway and that within this context habitat mapping takes on another layer of complexity.

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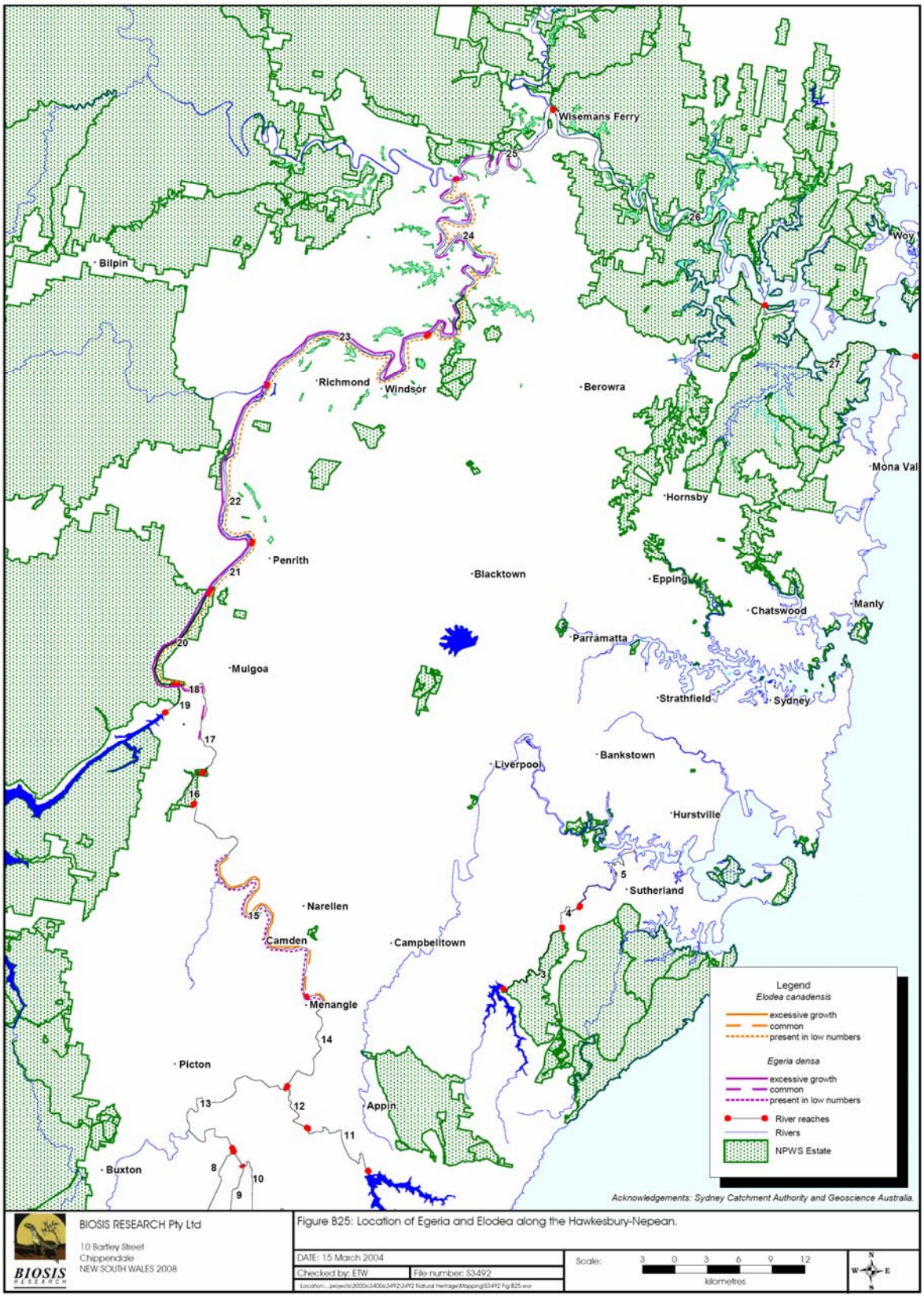
8. APPENDICES

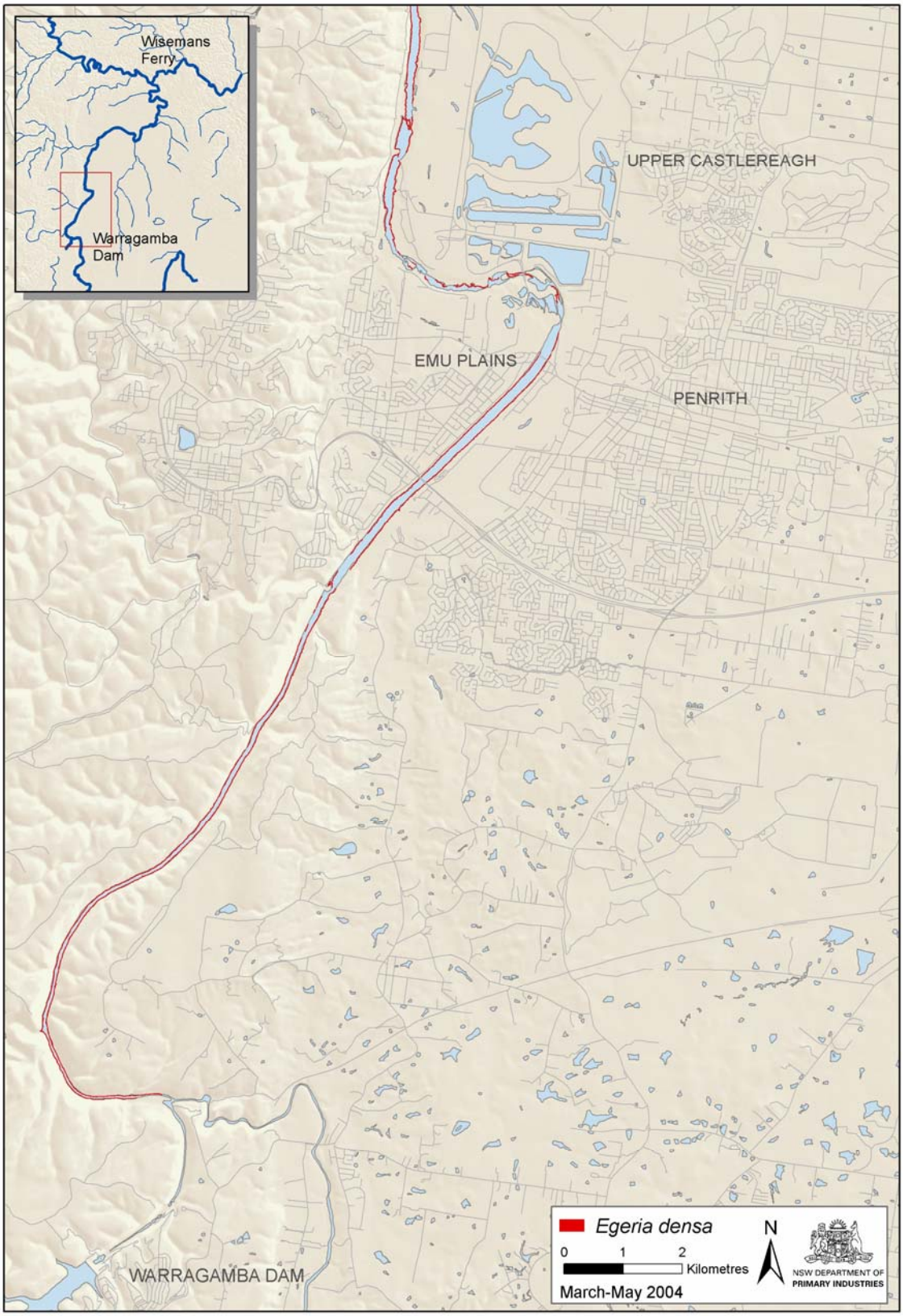
Appendix 1. Comparison of historical and recent estimates of area of seagrass for NSW estuaries (from Williams *et al*. 2003).

Estuary	Historical estimates of seagrass area West *et al.* (1985)		Recent estimates of seagrass area			Change					
	Date of airphoto	(ha)	Date of airphoto	(ha)	Refer-ence	Loss (ha)	L<40%	L>40%	Gain (ha)	G<40%	G>40%
Wallis Lake	1981	3078.5	1997	3190.0	1				111.5	X	
Hunter River	1981	0.0	1994	0.0	2	NA			NA		
Lake Macquarie	1981	1339.1	1997	1465.0	1				125.9	X	
Brisbane Waters	1981	549.0	1997	291.0	1	258.0		X			
Hawkesbury River	1977	47.0	1997	38.1	1	8.1	X				
Pittwater	1977	193.4	1997	192.0	1	1.4	X				
Georges River	1977	26.8	1998	76.4	3				49.6		X
Botany Bay	1977	340.3	1995	623.9	4				283.6		X
Hacking River	1977	86.9	1999	82.0	5	4.9	X				
St. Georges Basin	1979	853.8	1998	299.9	6	553.9		X			
Lake Conjola	1979	52.7	2001	24.2	1	28.5		X			
Burrill Lake	1979	50.8	2002	76.4	1				25.6		X
Tabourie Lake	1975	119.9	1998	21.9	1	98.0		X			
Durras Lake	1977	50.9	1998	49.6	1	1.3	X				
Lake Brou	1979	7.8	1998	0.0	1	7.8		X			
Mummuga Lake	1979	29.4	1998	31.5	1				2.1	X	
Wagonga Inlet	1979	148.4	1999	75.1	6	73.3		X			
Corunna Lake	1979	17.9	1998	15.7	1	2.2	X				
Wallaga Lake	1979	134.3	1998	108.4	1	25.9	X				
Bermagui River	1979	33.8	1998	28.1	6	5.7	X				
Merimbula Lake	1977	229.7	1994	163.8	7	65.9	X				
Pambula Lake	1977	86.8	1994	70.6	7	16.2	X				
Range	**1975 – 1981**	**0.0 – 3078.5**	**1994 – 2002**	**0.0 – 1465.0**		**1.3 – 553.9**			**2.1 – 283.6**		
Total		**7543.0**		**6999.5**		**1158.0**	**9**	**6**	**614.5**	**3**	**3**

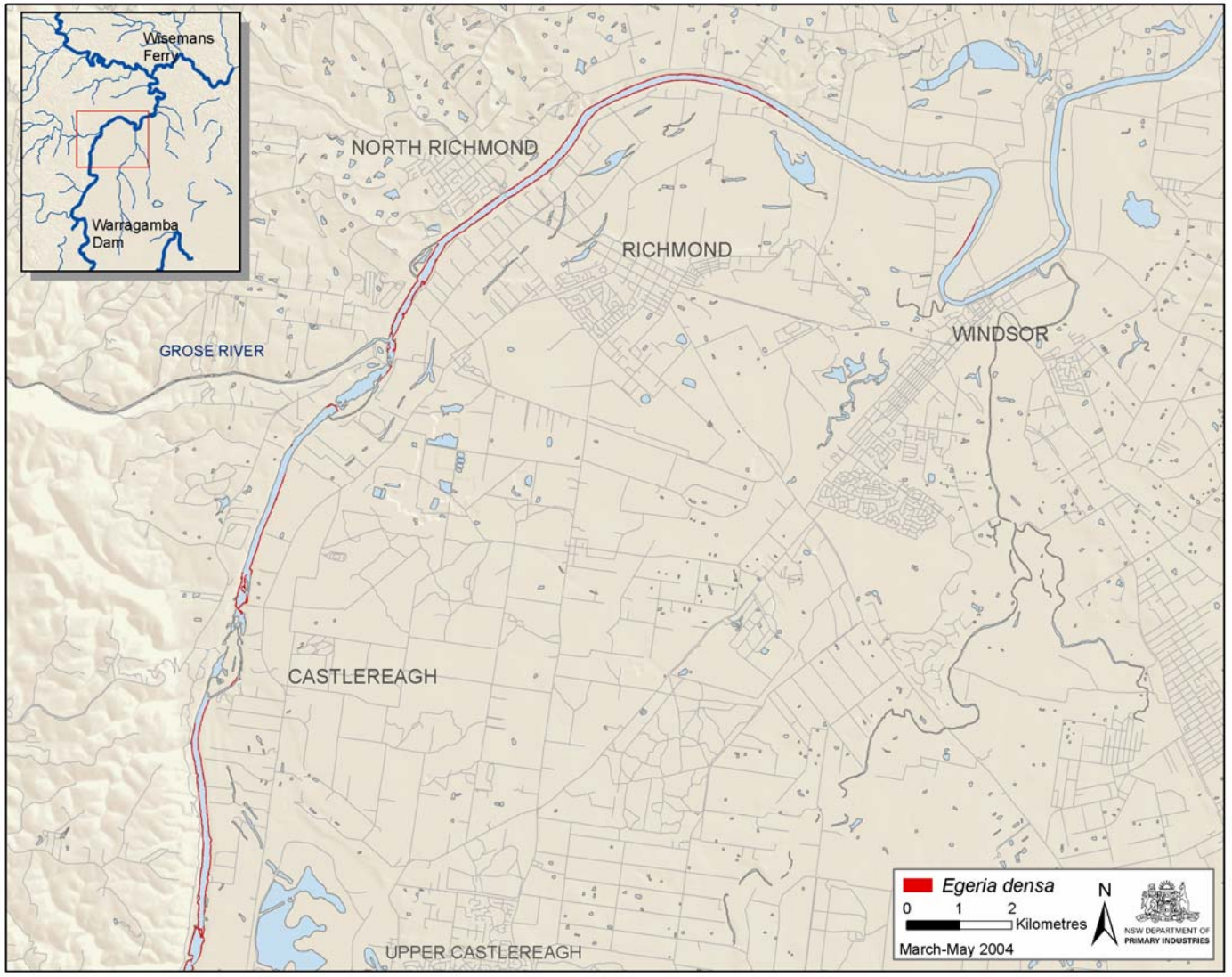
All historical estimates from West et al. (1985). References: 1.G. West, NSW DPI unpublished data; 2. Williams et al. (2000); 3. Pickthall et al. (2004); 4. Watford & Williams (1998); 5. Williams & Meehan (2004); 6. Meehan (2001); 7. Meehan (1997).



Appendix 2a. Map of the distribution of *Egeria densa* and *Elodea canadensis*, 2004, in the Hawkesbury Nepean River by E. Taylor-Wood of Biosis Research Pty Ltd.



Appendix 2b. Map of the distribution of *Egeria densa*, 2004. Details from Thiebaud *et al*. (in prep.).



Appendix 2c. Map of the distribution of *Egeria densa*, 2004. Details from Thiebaud *et al*. (in prep.).

Appendix 3. List of aerial photos used.

Photo Name	Scale	Date	Film No	Run	Frame #	Format	Source
Broken Bay	?	28.9.1955	NSW 229	6	5003	B&W	LPI
		28.9.1955	NSW 230	7	5003, 5005, 5006	B&W	LPI
		28.9.1955	NSW 230	8	5106, 5110	B&W	LPI
		28.9.1955	NSW 236	9	5034	B&W	LPI
		28.9.1955	NSW 237	10	5003	B&W	LPI
Gosford	?	18.3.1954	NSW 130	10	5003, 5012, 5031	B&W	Gosford Library
		18.3.1954	NSW 137	11	5070, 5073	B&W	Gosford Library
		18.3.1954	NSW 135	12	5118, 5119, 5127, 5129, 5134, 5137	B&W	Gosford Library
		18.3.1954	NSW 131	13	5111, 5112, 5113	B&W	Gosford Library
		18.3.1954	NSW 136	14	5027, 5029	B&W	Gosford Library
		18.3.1954	NSW 132	15	5060, 5068, 5069	B&W	Gosford Library
		18.3.1954	NSW 137	16	5011	B&W	Gosford Library
		18.3.1954	NSW 132	17	5125	B&W	Gosford Library
		18.3.1954	NSW 133	18	5011, 5012	B&W	Gosford Library
Gosford	?	16.5.1954	NSW 134	8	5052	B&W	Gosford Council
		16.5.1954	NSW 134	9	5041, 5043, 5044	B&W	Gosford Council
		16.5.1954	NSW 130	10	5014	B&W	Gosford Council
		16.5.1954	NSW 137	11	5059, 5061, 5071	B&W	Gosford Council
		16.5.1954	NSW 131	13	5104, 5107	B&W	Gosford Council
		16.5.1954	NSW 136	14	5017	B&W	Gosford Council
		16.5.1954	NSW 137	16	5014, 5017	B&W	Gosford Council
		16.5.1954	NSW 132	17	5120	B&W	Gosford Council
		16.5.1954	NSW 133	18	5014, 5016	B&W	Gosford Council
Cumberland	?	27.07.1955	NSW 225	1	5020	B&W	Hornsby Shire Council
		27.07.1955	NSW 225	2	5036, 5038, 5040	B&W	Hornsby Shire Council
		27.07.1955	NSW 225	3	5080, 5082	B&W	Hornsby Shire Council
		27.07.1955	NSW 226	4	5034, 5036	B&W	Hornsby Shire Council
		27.07.1955	NSW 226	5	5070	B&W	Hornsby Shire Council
		27.07.1955	NSW 229	6	5012, 5014, 5021	B&W	Hornsby Shire Council
		27.07.1955	NSW 230	7	5012, 5019	B&W	Hornsby Shire Council
		27.07.1955	NSW 230	8	5091, 5093, 5098	B&W	Hornsby Shire Council
		27.07.1955	NSW 236	9	5045	B&W	Hornsby Shire Council
		27.07.1955	NSW 237	10	5015	B&W	Hornsby Shire Council
Windsor	?	28.09.1955	NSW 229	6	5052	B&W	LPI
		28.09.1955	NSW 230	7	5054	B&W	LPI
		18.01.1956	NSW 236	8	5094	B&W	LPI
		18.01.1956	NSW 236	9	5084	B&W	LPI
		18.01.1956	NSW 237	10	5054	B&W	LPI
		17.10.1955	NSW 232	11	5057	B&W	LPI
		18.01.1956	NSW 237	12	5069	B&W	LPI
		17.10.1955	NSW 232	13	5174	B&W	LPI
		19.01.1956	NSW 238	14	5067, 5069	B&W	LPI
Liverpool	?	02.01.1956	NSW 234	15	5056, 5058	B&W	LPI
		21.06.1956	NSW 239	16	5136	B&W	LPI
		01.01.1956	NSW 233	19	5161	B&W	LPI
		08.1955	NSW 226	20	5161	B&W	LPI
		08.1955	NSW 227	21	5057, 5059	B&W	LPI
		08.1955	NSW 227	22	5086	B&W	LPI

Appendix 3 (continued) *List of aerial photos used*

Photo Name	Scale	Date	Film No	Run	Frame #	Format	Source
Sydney	1:16000	19.08.1986	NSW 3535	9	3, 33, 37, 41	Colour	LPI
		19.08.1986	NSW 3534	10	167, 203, 205	Colour	LPI
		19.08.1986	NSW 3534	11	106, 139, 146	Colour	LPI
		19.08.1986	NSW 3534	12	60, 98	Colour	LPI
		19.08.1986	NSW 3532	13	108, 149	Colour	LPI
		03.08.1986	NSW 3529	14	194	Colour	LPI
		19.08.1986	NSW 3534	15	43	Colour	LPI
		03.08.1986	NSW 3529	16	107, 109	Colour	LPI
		03.08.1986	NSW 3529	17	91, 93	Colour	LPI
		03.08.1986	NSW 3529	18	6	Colour	LPI
		03.08.1986	NSW 3528	20	118	Colour	LPI
		03.08.1986	NSW 3528	21	113	Colour	LPI
		03.08.1986	NSW 3528	22	23	Colour	LPI
		03.08.1986	NSW 3528	23w	2	Colour	LPI
Penrith	1:25000	12.08.1991	NSW 4028	2	61, 63	Colour	LPI
		12.08.1991	NSW 4028	3	92	Colour	LPI
	1:25000	10.10.1994	NSW 4245	3	185	Colour	LPI
		10.10.1994	NSW 4245	4	165	Colour	LPI
		10.10.1994	NSW 4245	5	111	Colour	LPI
		10.10.1994	NSW 4245	6	92	Colour	LPI
		06.10.1994	NSW 4245	7	37, 39	Colour	LPI
		06.10.1994	NSW 4245	8	8	Colour	LPI
		04.10.1994	NSW 4244	9	205	Colour	LPI
		04.10.1994	NSW 4244	10	193	Colour	LPI
Sydney	1:25000	18.03.2002	NSW 4727	3	118, 120	Colour	LPI
		18.03.2002	NSW 4727	4	112, 114	Colour	LPI
		18.03.2002	NSW 4727	5	171	Colour	LPI
Gosford	1:25000	18.03.2002	NSW 4728	11	16	Colour	LPI
		16.03.2002	NSW 4726	12	35, 37	Colour	LPI
Cumberland	1:16000	23.11.1997	QAS 3171c	14w	9110, 9111	Colour	Fisheries
		23.11.1997	QAS 3171c	15e	9118	Colour	Fisheries
		23.11.1997	QAS 3171c	15w	9120, 9122	Colour	Fisheries
		23.11.1997	QAS 3171c	16e	8274, 8276	Colour	Fisheries
		23.11.1997	QAS 3171c	16w	9140	Colour	Fisheries
		23.11.1997	QAS 3171c	17e	8282, 8284	Colour	Fisheries
		23.11.1997	QAS 3171c	17w	9146, 9147, 9153	Colour	Fisheries
		23.11.1997	QAS 3171c	18e	8309, 8313, 8317, 8319, 8321	Colour	Fisheries
		23.11.1997	QAS 3171c	19e	8330, 8332, 8338	Colour	Fisheries
		23.11.1997	QAS 3171c	20e	8361, 8363, 8365, 8367, 8371, 8373	Colour	Fisheries
		23.11.1997	QAS 3171c	21e	8385, 8387, 8389, 8391, 8393, 8395	Colour	Fisheries
		23.11.1997	QAS 3171c	23e	8462, 8467, 8469, 8474, 8475	Colour	Fisheries
		23.11.1997	QAS 3171c	24e	8479, 8486, 8492	Colour	Fisheries
		23.11.1997	QAS 3171c	25e	8534, 8540, 8545, 8546	Colour	Fisheries
		23.11.1997	QAS 3171c	26e	8552, 8558, 8561	Colour	Fisheries
		23.11.1997	QAS 3171c	27e	8616	Colour	Fisheries

Appendix 3 (continued) *List of aerial photos used*

Photo Name	Scale	Date	Film No	Run	Frame #	Format	Source
Sydney ISG	1:16000	20.08.1986	NSW 3536	1	14, 16	Colour	Gosford
		20.08.1986	NSW 3536	2	76	Colour	Gosford
		20.08.1986	NSW 3536	3	110, 111	Colour	Gosford
		20.08.1986	NSW 3536	4	141, 144	Colour	Gosford
		20.08.1986	NSW 3536	6e	203	Colour	Gosford
		19.08.1986	NSW 3535	7	124, 129	Colour	Gosford
		19.08.1986	NSW 3535	8	107	Colour	Gosford
Sydney ISG	1:16000	20.08.1986	NSW 3536	2	67, 68	Colour	Fisheries
		20.08.1986	NSW 3536	3	98, 105	Colour	Fisheries
		20.08.1986	NSW 3536	4	140, 145, 147, 149	Colour	Fisheries
		20.08.1986	NSW 3537	5	13, 20, 24	Colour	Fisheries
		20.08.1986	NSW 3536	6e	208	Colour	Fisheries
		19.08.1986	NSW 3535	7	126, 128	Colour	Fisheries
		19.08.1986	NSW 3535	8	103, 105	Colour	Fisheries
Cumberland	1:16000	09.12.1991	QAS 2767c	14w	3680	Colour	Baulkham Hills Council
		09.12.1991	QAS 2767c	15w	3683, 3686	Colour	Baulkham Hills Council
		28.01.1992	QAS 2772c	16w	4575	Colour	Baulkham Hills Council
		09.12.1991	QAS 2768c	17	3775, 3776	Colour	Baulkham Hills Council
		28.01.1992	QAS 2773c	18	4670	Colour	Baulkham Hills Council
		28.01.1992	QAS 2773c	19	4684	Colour	Baulkham Hills Council
		20.03.1992	QAS 2783c	20w	6863	Colour	Baulkham Hills Council
		20.03.1992	QAS 2783c	21	6904	Colour	Baulkham Hills Council
		20.03.1992	QAS 2783c	22	6962	Colour	Baulkham Hills Council
Cumberland	1:16000	17.03.1985	QAS 2327c	4w	4736	Colour	Baulkham Hills council
		17.03.1985	QAS 2327c	5w	4738, 4741	Colour	Baulkham Hills Council
		17.03.1985	QAS 2327c	6w	4803, 4804	Colour	Baulkham Hills Council
		17.03.1985	QAS 2327c	7	4814, 4816	Colour	Baulkham Hills Council
		17.03.1985	QAS 2327c	8	4890	Colour	Baulkham Hills Council
		17.03.1985	QAS 32331c	9	4919	Colour	Baulkham Hills Council
		17.03.1985	QAS 32331c	10	4986	Colour	Baulkham Hills Council
		17.03.1985	QAS 32331c	11	5026	Colour	Baulkham Hills Council
		17.03.1985	QAS 32331c	12	5084	Colour	Baulkham Hills Council
Cumberland	1:16000	17.03.1985	QAS 2327c	8	4875	Colour	Hornsby Shire Council
		17.03.1985	QAS 32331c	9	4932	Colour	Hornsby Shire Council
		17.03.1985	QAS 32331c	10	4972, 4974, 4975	Colour	Hornsby Shire Council
		17.03.1985	QAS 32331c	11	5041, 5043	Colour	Hornsby Shire Council
		01.04.1985	QAS 2332c	13	5235, 5242	Colour	Hornsby Shire Council
		01.04.1985	QAS 2332c	14	5306, 5308	Colour	Hornsby Shire Council
		01.04.1985	QAS 2332c	15	5377, 5379	Colour	Hornsby Shire Council
		01.04.1985	QAS 2332c	16e	5406	Colour	Hornsby Shire Council
		07.04.1985	QAS 2336c	17	5575	Colour	Hornsby Shire Council
Broken Bay	1:14550	1941	1311	2	3785, 3786, 3798	B&W	Fisheries
		1941	1309	3	4350, 4360, 4361, 4363, 4365	B&W	Fisheries
		1941	1309	3	4348	B&W	United Photo
		1941	1309	4	4437, 4439, 4441, 4445, 4446, 4448	B&W	Fisheries
		1941	1309	4	4434	B&W	United Photo

Appendix 3 (continued) *List of aerial photos used*

Photo Name	Scale	Date	Film No	Run	Frame #	Format	Source
		1941	1309	5	4476, 4478, 4481, 4483	B&W	Fisheries
		1941	1309	5	4471	B&W	United Photo
		1941	1313	7	3832, 3834	B&W	Fisheries
		1941	1313	7	3840, 3841, 3843, 3852, 3853	B&W	United Photo
		1941	1313	8e	3907	B&W	Fisheries
		1941	1313	8e	3904, 3915, 3917	B&W	United Photo
		1941	1313	9	3969, 3988	B&W	Fisheries
		1941	1313	9	3989	B&W	United Photo
		1941	1310	10	4104, 4109, 4111, 4049	B&W	Fisheries
		1941	1313	11	3925, 3926	B&W	Fisheries
		1941	1310	12	4140, 4153, 4154	B&W	Fisheries
		1941	1310	13	4037, 4068, 4070	B&W	United Photo
Gosford-Norahville	1:14550	25.11.1941	2571	12w	4596, 4597	B&W	Fisheries
		25.11.1941	2571	14	4565, 4550, 4551	B&W	Fisheries
		25.11.1941	2571	14	4564, 4561, 4563	B&W	United Photo
		25.11.1941	2569	15w	55152, 55153, 55166	B&W	Fisheries
		25.11.1941	1308	16	4180	B&W	Fisheries
		25.11.1941	1308	16	4189, 4190	B&W	United Photo
		25.11.1941	2569	17	55106, 55098	B&W	Fisheries
		25.11.1941	2571	18	4663, 4665, 4669, 4670, 4672, 4674, 4675	B&W	Fisheries
		25.11.1941	1308	19	4242	B&W	Fisheries
		25.11.1941	1308	19	4233, 4244	B&W	United Photo
Hawkesbury	/	2000	/	/	/	ECW	Hornsby Shire Council
Liverpool	1:32000	31.03.1949	SVY 549	1	5197	B&W	United photo
		31.03.1949	SVY 549	3	5147	B&W	United Photo
		31.03.1949	SVY 549	4	5105	B&W	United Photo
		31.03.1949	SVY 549	7	5132	B&W	United Photo
		09.05.1949	SVY 565	3a	5066	B&W	United Photo
Windsor	1:32000	31.03.1949	SVY 547	1	5221	B&W	United photo
		31.03.1949	SVY 549	2	5228	B&W	United Photo
		07.02.1949	SVY 521	3	5022, 5024, 5027	B&W	United Photo
		07.02.1949	SVY 521	4	5049	B&W	United Photo
		07.02.1949	SVY 521	5	5082	B&W	United Photo
		07.02.1949	SVY 521	6	5100	B&W	United Photo

Appendix 4. Details of the ortho-rectification process by year of aerial photo.

	Fiducial error (mean)	**Ground Control Points (mean)**	**RMS error (mean)**
1941	NA	9.5	4.1021
1954	NA	9.9	3.9036
1955	NA	9.5	4.0030
1985	1.4554	10.2	6.3800
1986	0.8717	9.9	3.8016
1991	1.1723	10	3.0818
1992	1.6367	10.8	7.6799
1994	0.7782	10	2.4464
1997	1.5243	9.9	5.6141
2002	1.714	9.9	3.5785

Appendix 5. Comparison of classification (ha) for the 2000s before and after field validation by Location and Site. Increases are shown in blue text, decreases in red.

		Natural vegetation	Agricultural land	Residential area	Industrial area	Golf course	Park	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
Location 1																
2000s																
	S1	21.63	0	47.05		7.54	10.28	10.33						96.61	0	0
	S2	4.99	0	163.55		0	14.35	2.04						42.21	13.93	1.36
	S3	0	0	202.64		21.29	16.15	0						2.24	0.97	0.09
	S4	0	0	52.85		0	0.24	0.35						4.06	0	0
	S5	139.86	0	20.83		0	0	0						2.86	1.23	0
	S6	236.74	0	19.45		0	7.44	5.19						9.86	0.19	0
total		403.22	0.00	506.37		28.83	48.47	17.91						157.85	16.32	1.45
After field validation	S1	21.63	0	47.05		7.54	10.28	10.33						98.06	0	0
	S2	4.99	0	163.55		0	14.35	2.04						42.21	13.93	1.36
	S3	0	0	202.64		21.29	16.15	0						2.60	1.09	0.09
	S4	0	0	52.85		0	0.24	0.35						5.57	0	0
	S5	139.86	0	20.83		0	0	0						3.27	1.25	0
	S6	236.74	0	19.45		0	7.44	5.19						9.62	0.19	0
total		403.22	0.00	506.37		28.83	48.47	17.91						161.34	16.46	1.45
Location 2																
2000s																
	S1	204.41					0							1.17	0.50	0.14
	S2	55.84					0							0.30	0.05	0
	S3	331.90					0							0	7.14	0
	S4	213.43					2.79							0	4.45	0
	S5	119.11					2.73							0.26	0.82	0
	S6	411.66					0							0.99	1.15	0.15
total		1336.33					5.53							2.71	14.10	0.30

Appendix 5 (continued) *Comparison of classification (ha) for the 2000s before and after field validation by Location and Site.*

		Natural vegetation	Agricultural land	Residential area	Industrial area	Golf course	Park	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
After field validation	S1	204.41					0							1.31	0.50	0.14
	S2	55.84					0							0.32	0.05	0
	S3	331.27					0							0.54	7.76	0
	S4	213.43					2.79							0	4.45	0
	S5	119.11					2.73							0.28	0.82	0
	S6	411.66					0							1.35	1.15	0.15
total		1335.71					5.53							3.80	14.73	0.30
Location 3																
2000s																
	S1	561.28	0.40	0			0	0				0		0	42.14	3.86
	S2	234.78	0	0.69			0	0				2.96		2.74	1.23	0
	S3	171.03	0.28	0			0	0				0		0	3.25	0
	S4	385.90	0	24.21			0.67	6.27				0		31.27	56.07	8.74
	S5	184.87	0	40.10			9.37	0				5.33		0.68	14.69	1.00
	S6	113.70	0	0			0	0				0		0	3.46	0
total		1651.55	0.68	65.00			10.03	6.27				8.29		34.69	120.84	13.60
After field validation	S1	560.53	0.40	0			0	0				0		0	42.89	3.86
	S2	234.78	0	0.69			0	0				2.96		2.79	1.23	0
	S3	171.03	0.28	0			0	0				0		0	3.25	0
	S4	385.63	0	24.21			0.67	6.27				0		31.42	56.31	8.74
	S5	184.73	0	40.10			9.37	0				5.33		0.68	14.83	1.00
	S6	113.70	0	0			0	0				0		0	3.46	0
total		1650.40	0.68	65.00			10.03	6.27				8.29		34.89	121.96	13.60

Appendix 5 (continued) *Comparison of classification (ha) for the 2000s before and after field validation by Location and Site.*

		Natural vegetation	Agricultural land	Residential area	Industrial area	Golf course	Park	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
Location 4																
2000s																
	S1	0	0	30.53			0	0				0		11.23	0	0
	S2	92.12	11.89	39.96			4.18	0				10.31		0	20.27	0
	S3	101.50	0	0			0	0				0		0.68	40.04	0.80
	S4	230.35	1.16	0			0	0				0		2.08	53.99	1.66
	S5	98.71	0	3.34			0	0				0		0	17.75	3.10
	S6	96.98	28.09	0			0	0				0		0	58.95	33.22
total		619.67	41.14	73.84			4.18	0.00				10.31		14.00	191.00	38.78
After field validation	S1	0	0	30.53			0	0				0		12.07	0	0
	S2	92.01	11.89	39.96			4.18	0				10.31		0	20.38	0
	S3	101.50	0	0			0	0				0		0.68	40.04	0.80
	S4	230.35	1.16	0			0	0				0		2.08	53.99	1.66
	S5	98.71	0	3.34			0	0				0		0	17.75	3.10
	S6	96.98	28.09	0			0	0				0		0	58.95	33.22
total		619.56	41.14	73.84			4.18	0.00				10.31		14.84	191.11	38.78
Location 5																
2000s																
	S1	244.02	0	0										0	11.93	0
	S2	496.81	7.03	0										1.64	14.29	2.54
	S3	266.78	0	0										0.88	10.52	0.36
	S4	386.76	0	2.12										0	28.41	0.46
	S5	141.75	0	1.24										0	20.12	0.11
	S6	806.12	8.01	0										0	93.88	5.07
total		2342.24	15.04	3.36										2.53	179.15	8.55

Appendix 5 (continued) *Comparison of classification (ha) for the 2000s before and after field validation by Location and Site.*

		Natural vegetation	Agricultural land	Residential area	Industrial area	Golf course	Park	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
After field validation	S1	244.02	0	0										0	11.93	0
	S2	496.81	6.82	0										2.63	14.50	2.54
	S3	266.78	0	0										0.55	10.52	0.36
	S4	386.52	0	2.12										0	28.65	0.46
	S5	141.75	0	1.24										0	20.12	0.11
	S6	806.04	8.01	0										0.61	94.15	4.87
total		2341.93	14.84	3.36										3.78	179.86	8.35
Location 6																
2000s																
	S1	136.81	27.69	0								0			26.65	32.62
	S2	191.61	2.21	7.49								0			53.78	1.35
	S3	156.65	36.41	5.82								4.46			109.33	7.58
	S4	177.24	34.52	0								0			19.38	50.74
	S5	141.33	7.52	8.38								0			5.18	16.88
	S6	65.70	0	0								0			4.67	1.76
total		869.34	108.36	21.69								4.46			218.98	110.93
After field validation	S1	136.81	27.69	0								0			26.65	32.62
	S2	191.61	2.21	7.49								0			53.78	1.35
	S3	156.90	36.41	5.82								4.46			109.39	7.58
	S4	176.93	34.52	0								0			19.70	50.74
	S5	140.97	7.52	8.38								0			5.54	16.88
	S6	65.70	0	0								0			4.67	1.76
total		868.91	108.36	21.69								4.46			219.73	110.93

Appendix 5 (continued) *Comparison of classification (ha) for the 2000s before and after field validation by Location and Site.*

		Natural vegetation	Agricultural land	Residential area	Industrial area	Golf course	Park	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
Location 7																
2000s																
	S1	104.52	66.62	6.36											18.86	9.33
	S2	14.48	46.34	9.57											33.21	0.54
	S3	65.11	36.62	0											7.88	0
	S4	93.10	41.66	0											13.32	0
	S5	47.80	23.70	0											3.47	0
	S6	10.52	59.88	0											3.18	0
total		335.52	274.82	15.93											79.91	9.87
After field validation	S1	104.52	66.62	6.36											18.86	9.33
	S2	14.48	46.34	9.57											33.21	0.54
	S3	65.11	36.62	0											7.88	0
	S4	92.56	41.66	0											13.86	0
	S5	47.80	23.70	0											3.47	0
	S6	10.52	59.88	0											3.18	0
total		334.98	274.82	15.93											80.45	9.87

Appendix 6. Metadata statement.

Metadata Category	Core Metadata Element	Description
Dataset	Title	Hawkesbury Lower Nepean Aquatic Habitat Study: Developing a monitoring framework
	Custodian	NSW Department of Primary Industries
	Jurisdiction	New South Wales
Description	Abstract	Historical assessment of the changes in aquatic habitat and land cover along the Hawkesbury Nepean River
	Search Word(s)	ECOLOGY Habitat FISHERIES LAND cover VEGETATION
	Geographic Extent Name(s)	New South Wales
	GEN Category	1:100 000
	GEN Custodial Jurisdiction	New South Wales
	GEN Name	ST ALBANS 9031, 1:100 000 Map Sheet GOSFORD 9131, 1:100 000 Map Sheet PENRITH 9030, 1:100 000 Map Sheet SYDNEY 9130, 1:100 000 Map Sheet
	Geographic Extent Polygon(s)	
	Geographic Bounding Box	
	North Bounding Latitude	-33.364368
	South Bounding Latitude	-33.898847
	East Bounding Longitude	151.342248
	West Bounding Longitude	150.580615
Data currency	Beginning date	OCT2004
	Ending date	MAY2006
Dataset status	Progress	Complete
	Maintenance and update frequency	Not planned
Access	Stored Data Format	6 shapefiles: Hawkesbury_1940s Hawkesbury_1950s Hawkesbury_1980s Hawkesbury_1990s Hawkesbury_2000s Hawkesbury_2000s_Field NON DIGITAL Maps and Tables
	Available format types	DIGITAL Arcview shapefiles NON DIGITAL Maps and Tables
	Access constraints	Use of this data is subject to approved license agreement. Please refer any request of this data to the NSW Department of Primary Industries. Please do not distribute this data set.

Appendix 6 (continued) *Metadata statement.*

Metadata Category	Core Metadata Element	Description
Data Quality	Lineage	Data Collection Method: Aerial photography interpretation. Data Set Source: The data has been prepared from Land and Property Information photo runs. Source Material Input Scale: 1: 14 550 (1941); 1: 16 000 (1985, 1986, 1991, 1997); 1: 25 000 (1991, 2002); 1: 32 000 (1949) Additional Processing Steps: The aerial photographs were scanned into TIFF format files and imported into ERDAS IMAGINE as image files for orthorectification. The digital images were orthorectified using a Digital Elevation Model and Digital Topographic Database provided by Land and Property Information. The boundaries of habitat (Mangrove, Saltmarsh, Seagrass) and land cover features (Agricultural area, Residential area, Industrial area, Natural vegetation, Passive recreational area, Bare sand, Bare earth, Dry riverbed, Reservoir, Roads and Dam wall) were digitised and edited in Arcview.
	Positional accuracy	All data was mapped at a scale of 1:3000 derived from orthorectified aerial photographs with a positional accuracy of less than 10 metres.
	Attribute accuracy	Boundaries were identified on orthorectified aerial photographs. Boundary locations were verified in the field. Area calculations were determined in Arcview.
	Logical consistency	Not Known
	Completeness	Complete
Contact Address	Contact organisation	NSW Department of Primary industries
	Contact position	Technician – Habitat Mapping
	Mail Address 1	Port Stephens Research Centre Locked Bag 1
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	Suburb/Place/Locality	Nelson Bay
	State	NSW
	Country	Australia
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	Electronic mail address	Isabelle.Thiebaud@dpi.nsw.gov.au
Metadata Date	Metadata date	May2006
Additional Metadata	Additional Metadata	
Page 1 Information	Project Name	
	Project Number	

Appendix 6 (continued) *Metadata statement.*

Metadata Category	Core Metadata Element	Description
Extended Description Details	Type of feature	Polygon data, digitised data
	Attribute/Field List	Features, Perimeter, Area, Hectares, Location
	Attribute/Field Description	Features = habitat and landcover type Perimeter = kilometres Area = kilometres Hectares Location = Location and Site number
Dataset Environment	Software	Arcview 9.1
	Computer Operating System	
	Dataset Size	

Appendix 7. Change in land cover and habitat (ha) by Location and Site. NM (Not Mappable) refers to the poor quality of some aerial photos which prevented the mapping of certain features; NA (Not Available) refers to the unavailability of aerial photos for a particular year/section of the river.

		Natural vegetation	Agricultural land	Residential land	Industrial area	Golf course	Golf park	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
Location 1																
1940s																
1941	S1	28.34	0	34.18		7.43	6.49	28.46						120.3	0	0
1941	S2	157.15	4.04	11.61		0	0	5.4						41.23	2.22	16.23
1941	S3	73.15	88.8	55.93		0	0	0						9.57	4.39	19.81
1941	S4	51.17	0	2.59		0	0	4.08						14.53	0	0
1941	S5	151.3	0	8.28		0	0	0.78						7.91	0.73	0
1941	S6	250.33	1.05	0.62		0	6.3	13.41						26.62	0.06	0
total		**711.44**	**93.89**	**113.2**		**7.43**	**12.79**	**52.13**						**220.16**	**7.4**	**36.03**
1950s																
1955	S1	17.45	0	41.93		7.6	8.34	28.81						74.94	0	0
1955	S2	69.54	0	102.41		0	0	3.47						24.13	8.34	13.82
1955	S3	64.94	40.01	90.26		19.36	0	0						9.12	4.43	19.02
1955	S4	48.65	0	5.22		0	0	NM						NM	0	0
1955	S5	149.8	0	8.78		0	0	0.58						4.68	1.23	0
1955	S6	248.72	0	4.34		0	6.94	12.27						11.84	0.05	0
total		**599.1**	**40.01**	**252.93**		**26.96**	**15.28**	**45.13**						**124.71**	**14.05**	**32.84**
1980s																
1986	S1	12.03	0	47.69		7.39	10.5	22.24						105.57	0	0
1986	S2	5.1	0	162.36		0	15.07	4.28						44.08	12.86	1.5
1986	S3	0	0	201.99		22.04	17.56	0						15.53	0.81	0.14
1986	S4	0	0	54.4		0	0.47	2.65						7.26	0	0
1986	S5	146.23	0	14.3		0	0	0.42						6.55	1.36	0
1986	S6	238.08	0	16.26		0	6.66	13.13						17.49	0.15	0
total		**401.44**	**0**	**496.99**		**29.43**	**50.26**	**42.72**						**196.47**	**15.19**	**1.64**

Appendix 7 (continued) *Change in land cover and habitat (ha) by Location and Site.*

		Natural vegetation	Agricultural land	Residential land	Industrial area	Golf course	Golf park	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
1990s																
1997	S1	20.23	0	48.52		7.67	9.78	15.83						94.28	0	0
1997	S2	5.01	0	162.22		0	15.46	2.9						38.91	12.46	2.16
1997	S3	0	0	201.84		21.75	16.81	0						9.71	0.76	0.1
1997	S4	0	0	52.97		0	0.19	1.08						8.1	0	0
1997	S5	137.94	0	20.66		0	0	0.27						4.31	1.22	0
1997	S6	235.72	0	18.38		0	6.92	9.64						14.67	0.12	0
total		**398.9**	**0**	**504.58**		**29.42**	**49.16**	**29.72**						**169.99**	**14.55**	**2.26**
2000s																
2002	S1	21.63	0	47.05		7.54	10.28	10.33						96.61	0	0
2002	S2	4.99	0	163.55		0	14.35	2.04						42.21	13.93	1.36
2002	S3	0	0	202.64		21.29	16.15	0						2.24	0.97	0.09
2002	S4	0	0	52.85		0	0.24	0.35						4.06	0	0
2002	S5	139.86	0	20.83		0	0	0						2.86	1.23	0
2002	S6	236.74	0	19.45		0	7.44	5.19						9.86	0.19	0
total		**403.22**	**0**	**506.37**		**28.83**	**48.47**	**17.91**						**157.85**	**16.32**	**1.45**
Location 2																
1940s																
1941	S1	204.08					0							1.26	0.41	0.35
1941	S2	54.9					0							0.22	0.07	0
1941	S3	329.27					0							1.06	6.63	0.34
1941	S4	211.23					0							0	3.66	2.02
1941	S5	118					0							0.37	1.32	0.22
1941	S6	412.56					0							1.79	0.66	0.59
total		**1330.05**					**0**							**4.71**	**12.75**	**3.51**

Appendix 7 (continued) *Change in land cover and habitat (ha) by Location and Site.*

		Natural vegetation	Agricultural land	Residential land	Industrial area	Golf course	Golf park	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
1950s																
1955	S1	204.56					0							1.28	0.53	0.38
1955	S2	54.89					0							0.14	0.1	0
1955	S3	328.44					0							1.27	7.06	0.17
1955	S4	210.71					2.3							0	4.34	1.3
1955	S5	119.66					0							0.7	0.88	0.08
1955	S6	411.25					0							0.98	0.7	0.2
total		**1329.5**					**2.3**							**4.36**	**13.61**	**2.13**
1980s																
1985	S1	203.64					0							2	0.49	0.18
1985	S2	54.97					0							0.33	0.08	0
1985	S3	329					0							0	8.63	0
1985	S4	212.07					2.77							0	4.97	0
1985	S5	118.8					2.88							0.23	0.82	0
1985	S6	412.64					0							1.87	1.28	0.2
total		**1331.12**					**5.65**							**4.43**	**16.27**	**0.38**
1990s																
1997	S1	203.61					0							1.52	0.53	0.11
1997	S2	55.61					0							0.3	0.05	0
1997	S3	330.26					0							0	8.32	0
1997	S4	212.54					2.71							0	4.84	0
1997	S5	118.66					2.84							0.38	0.73	0
1997	S6	410.97					0							0.92	1.2	0.15
total		**1331.64**					**5.55**							**3.13**	**15.66**	**0.26**

Appendix 7 (continued) *Change in land cover and habitat (ha) by Location and Site.*

		Natural vegetation	Agricultural land	Residential land	Industrial area	Golf course	Golf park	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
2000s																
2000	S1	204.41					0							1.17	0.5	0.14
2000	S2	55.84					0							0.3	0.05	0
2000	S3	331.9					0							0	7.14	0
2000	S4	213.43					2.79							0	4.45	0
2000	S5	119.11					2.73							0.26	0.82	0
2000	S6	411.66					0							0.99	1.15	0.15
total		**1336.33**					**5.53**							**2.71**	**14.1**	**0.3**
Location 3																
1940s																
1941	S1	552.52	1.25	0		0	0				0			0	29.51	12.65
1941	S2	232.92	2.48	0		0	0				2.8			1.57	0.79	0.49
1941	S3	168.83	0.45	0		0	0				0			0	1.91	0.35
1941	S4	391.6	1.11	15.81		0	5.17				0			31.8	42.89	23.52
1941	S5	192.18	21.64	17.08		2.31	0				1.96			0	11.16	5.21
1941	S6	112.87	3	0		0	0				0			0	0.91	1.01
total		**1650.92**	**29.92**	**32.88**		**2.31**	**5.17**				**4.77**			**33.37**	**87.17**	**43.24**
1950s																
1954	S1	555.52	1.14	0		0	0				0			0	32.07	8.6
1954	S2	230.8	3.02	0		0	0				3.25			1.24	0.7	0.48
1954	S3	169.59	0.36	0		0	0				0			0	2.06	0.22
1954	S4	388.84	1.27	19.14		0	5.8				0			34.91	42.31	21.46
1954	S5	194.26	6.07	28.57		3.07	0				2.24			0	9.91	4.58
1954	S6	113.5	2.42	0		0	0				0			0	1.16	1
total		**1652.51**	**14.28**	**47.71**		**3.07**	**5.8**				**5.5**			**36.15**	**88.21**	**36.34**

Appendix 7 (continued) *Change in land cover and habitat (ha) by Location and Site.*

		Natural vegetation	Agricultural land	Residential land	Industrial area	Golf course	Golf park	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
1980s																
1986	S1	556.62	0.44	0		0	0				0			0	42.28	5.24
1986	S2	233.48	0	0.95		0	0				3.24			4.5	0.93	0.23
1986	S3	170.52	0.32	0		0	0				0			0	2.55	0
1986	S4	384.48	0	19.71		0.73	9.08				0			33.82	51.96	14.94
1986	S5	191.54	0	31.73		9.53	0				5.28			0	13.16	1.12
1986	S6	113.05	0.42	0		0	0				0			0	2.87	0
total		**1649.69**	**1.18**	**52.38**		**10.26**	**9.08**				**8.52**			**38.32**	**113.74**	**21.53**
1990s																
1997	S1	561.77	0.35	0		0	0				0			0	40.4	4.24
1997	S2	233.73	0	0.62		0	0				3.09			2.82	1.14	0.06
1997	S3	169.57	0.54	0		0	0				0			0	2.85	0
1997	S4	387.02	0	23.75		0.63	6.62				0			31.24	53.35	9.29
1997	S5	183.76	0	38.84		10.43	0				5.86			0.7	13.37	1.21
1997	S6	115.54	0	0		0	0				0			0	2.92	0
total		**1651.39**	**0.89**	**63.21**		**11.06**	**6.62**				**8.95**			**34.76**	**114.03**	**14.8**
2000s																
2000	S1	561.28	0.4	0		0	0				0			0	42.14	3.86
2000	S2	234.78	0	0.69		0	0				2.96			2.74	1.23	0
2000	S3	171.03	0.28	0		0	0				0			0	3.25	0
2000	S4	385.9	0	24.21		0.67	6.27				0			31.27	56.07	8.74
2000	S5	184.87	0	40.1		9.37	0				5.33			0.68	14.69	1
2000	S6	113.7	0	0		0	0				0			0	3.46	0
total		**1651.55**	**0.68**	**65**		**10.03**	**6.27**				**8.29**			**34.69**	**120.84**	**13.6**

Appendix 7 (continued) *Change in land cover and habitat (ha) by Location and Site.*

		Natural vegetation	Agricultural land	Residential land	Industrial area	Golf course	Golf park	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
Location 4																
1940s																
1941	S1	21.45	0	10.51		0	0.4							2.29	0	0
1941	S2	118.02	14.42	17.46		0	0							0	13.22	0
1941	S3	93.8	0	0		0	0							0	34.22	9.16
1941	S4	256.75	1.97	0		0	0							0	16.95	11.2
1941	S5	93.31	1.84	0		0	0							0	3.17	23.92
1941	S6	73.82	49.04	0		0	0							0	33.64	52.95
total		**657.16**	**67.27**	**27.97**		**0**	**0.4**							**2.29**	**101.21**	**97.22**
1950s																
1954	S1	15.79	0	15.47		0	0.43							NM	0	0
1954	S2	95.72	30.33	22.38		0	0							0	15.28	0
1954	S3	97.65	0	0		0	0							0	36.19	3.16
1954	S4	233.28	1.84	0		0	0							0	46.03	7.7
1954	S5	95.52	2.82	0		0	0							0	2.91	20.84
1954	S6	72.99	47.19	0		0	0							0	38.24	51.34
total		**610.95**	**82.18**	**37.85**		**0**	**0**							**0**	**138.65**	**83.04**
1980s																
1986	S1	0	0	30.67		0	0.39				0			2.48	0	0
1986	S2	90.59	14.29	39.46		2.54	0				10.87			0	17.76	0
1986	S3	99.52	0	0		0	0				0			0	37.55	1.7
1986	S4	231.87	1.17	0		0	0				0			0	55.28	1.13
1986	S5	98.1	1.93	1.08		0	0				0			0	17.06	3.9
1986	S6	83.77	40.01	0		0	0				0			0	52.73	38.64
total		**603.85**	**57.4**	**71.22**		**2.54**	**0.39**				**10.87**			**2.48**	**180.37**	**45.36**

Appendix 7 (continued) *Change in land cover and habitat (ha) by Location and Site.*

		Natural vegetation	Agricultural land	Residential land	Industrial area	Golf course	Golf park	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
1990s																
1997	S1	0	0	30.93		0	0.38				0			9.3	0	0
1997	S2	91.05	12.03	39.87		4.23	0				10.38			0	20.23	0
1997	S3	99.19	0	0		0	0				0			0	38.75	1.32
1997	S4	234.9	1.12	0		0	0				0			0	53.13	1.26
1997	S5	99.45	1.99	1.12		0	0				0			0	16.36	3.46
1997	S6	90.91	32.16	0		0	0				0			0	56.81	35.06
total		**615.51**	**47.31**	**71.92**		**4.23**	**0.38**				**10.38**			**9.3**	**185.29**	**41.09**
2000s																
2000	S1	0	0	30.53		0	0				0			11.23	0	0
2000	S2	92.12	11.89	39.96		4.18	0				10.31			0	20.27	0
2000	S3	101.5	0	0		0	0				0			0.68	40.04	0.8
2000	S4	230.35	1.16	0		0	0				0			2.08	53.99	1.66
2000	S5	98.71	0	3.34		0	0				0			0	17.75	3.1
2000	S6	96.98	28.09	0		0	0				0			0	58.95	33.22
total		**619.67**	**41.14**	**73.84**		**4.18**	**0**				**10.31**			**14**	**191**	**38.78**
Location 5																
1940s																
1941	S1	242.73	0	0										0	9.43	1.52
1941	S2	488.94	9.83	0										12.65	8.75	8.42
1941	S3	265.35	0	0										0.94	8.65	1.42
1941	S4	385.99	0	0										0	23.56	2.27
1941	S5	141.04	0	0.59										0	16.29	0.39
1941	S6	778.24	12.32	0										0	76.6	26.66
total		**2302.29**	**22.14**	**0.59**										**13.59**	**143.28**	**40.68**

Appendix 7 (continued) *Change in land cover and habitat (ha) by Location and Site.*

		Natural vegetation	Agricultural land	Residential land	Industrial area	Golf course	Golf park	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
1950s																
1955	S1	242.8	0	0										0	9.73	0.45
1955	S2	491.26	6.89	0										NM	8.71	7.29
1955	S3	265.54	0	0										NM	8.09	0.79
1955	S4	388.67	0	0										0	23.75	1.8
1955	S5	141.82	0	0.82										0	16	0.36
1955	S6	789.56	12.49	0										0	78.23	16.99
total		**2319.65**	**19.37**	**0.82**										**0**	**144.53**	**27.69**
1980s																
1985	S1	242.05	0	0										0	11.79	0.39
1985	S2	497.97	5.93	0										1.99	11.6	3.05
1985	S3	266.04	0	0										1.51	9.96	0.73
1985	S4	386.24	0	0.4										0	25.05	1.55
1985	S5	140.79	0	0.79										0	19.05	0.41
1985	S6	796.06	11.02	0										0	91.22	6.88
total		**2329.15**	**16.96**	**1.18**										**3.5**	**168.66**	**13**
1990s																
1997	S1	241.99	0	0										0	12.37	0.31
1997	S2	498.23	4.91	0										3.98	12.81	2.43
1997	S3	266.66	0	0										0.97	10.37	0.37
1997	S4	387.46	0	2.12										0	26.75	0.68
1997	S5	142.51	0	1.04										0	19.38	0.19
1997	S6	800.59	9.34	0										0	95.22	4.21
total		**2337.45**	**14.25**	**3.16**										**4.95**	**176.9**	**8.19**

Appendix 7 (continued) *Change in land cover and habitat (ha) by Location and Site.*

		Natural vegetation	Agricultural land	Residential land	Industrial area	Golf course	Golf park	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
2000s																
2000	S1	244.02	0	0										0	11.93	0
2000	S2	496.81	7.03	0										1.64	14.29	2.54
2000	S3	266.78	0	0										0.88	10.52	0.36
2000	S4	386.76	0	2.12										0	28.41	0.46
2000	S5	141.75	0	1.24										0	20.12	0.11
2000	S6	806.12	8.01	0										0	93.88	5.07
total		**2342.24**	**15.04**	**3.36**										**2.53**	**179.15**	**8.55**
Location 6																
1940s																
1941	S1	126.89	10.97	0											0	73.93
1941	S2	180.42	15.56	0											0	9.4
1941	S3	161.98	32.55	0											5.01	24.62
1941	S4	175.7	23.81	0											0	70.37
1941	S5	112.15	26.23	0											0	36.58
1941	S6	59.19	0.51	0											0	10.7
total		**816.34**	**109.62**	**0**											**5.01**	**225.61**
1950s																
1954	S1	136.81	4.65	0											0	62.28
1954	S2	190.28	10.89	0											0	8.08
1954	S3	169.14	27.83	0.64											4.56	17.99
1954	S4	163.51	35.45	0											0	69.35
1954	S5	115.55	21.01	0											0	38.23
1954	S6	63.66	0.41	0											0	3.93
total		**838.95**	**100.24**	**0.64**											**4.56**	**199.86**

Appendix 7 (continued) *Change in land cover and habitat (ha) by Location and Site.*

		Natural vegetation	Agricultural land	Residential land	Industrial area	Golf course	Golf park	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
1980s																
1986	S1	136	27.18	0											0	35.39
1986	S2	191.11	2.14	6.54											0	1.23
1986	S3	157.48	36.4	3.33											4.7	8.92
1986	S4	167.05	27.13	0											0	67.81
1986	S5	128.95	10.06	4.97											0	31.52
1986	S6	66.53	0.4	0											0	2.35
total		**847.12**	**103.32**	**14.85**											**4.7**	**147.23**
1990s																
1997	S1	133.32	31.63	0											0	33.86
1997	S2	187.35	3.12	8.18											0	1.31
1997	S3	158.01	34.95	6.25											4.46	7.82
1997	S4	167.93	38.82	0											0	57.22
1997	S5	127.12	10.16	9.26											0	27.62
1997	S6	65.19	0.5	0											0	2.4
total		**838.91**	**119.17**	**23.69**											**4.46**	**130.24**
2000s																
2002	S1	136.81	27.69	0											0	32.62
2002	S2	191.61	2.21	7.49											0	1.35
2002	S3	156.65	36.41	5.82											4.46	7.58
2002	S4	177.24	34.52	0											0	50.74
2002	S5	141.33	7.52	8.38											0	16.88
2002	S6	65.7	0	0											0	1.76
total		**869.34**	**108.36**	**21.69**											**4.46**	**110.93**

Appendix 7 (continued) *Change in land cover and habitat (ha) by Location and Site.*

		Natural vegetation	Agricultural land	Residential land	Industrial area	Golf course	Golf park	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
Location 7																
1940s																
1941	S1	99.25	59.88	0												26.03
1941	S2	21.73	44.99	0												4.58
1941	S3	58.13	45.07	0												0
1941	S4	75.11	58.9	0												0
1941	S5	41.27	31.48	0												0
1941	S6	8.47	63.45	0												0
total		**303.97**	**303.78**	**0**												**30.61**
1950s																
1954	S1	107.77	54.49	0												23.46
1954	S2	23.71	41.86	0												3.48
1954	S3	59.99	43.13	0												0
1954	S4	102.79	35.12	0												0
1954	S5	44.68	27.19	0												0
1954	S6	9.36	60.59	0												0
total		**348.29**	**262.38**	**0**												**26.94**
1980s																
1986	S1	102.54	70.45	2.43												14.65
1986	S2	18.82	47.51	4.86												0.58
1986	S3	61.97	40.6	0												0
1986	S4	80.68	56.35	0												0
1986	S5	45.99	25.79	0												0
1986	S6	9.29	60.33	0												0
total		**319.3**	**301.04**	**7.28**												**15.22**

Appendix 7 (continued) *Change in land cover and habitat (ha) by Location and Site.*

		Natural vegetation	Agricultural land	Residential land	Industrial area	Golf course	Golf park	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
1990s																
1997	S1	99.89	69	5.95												10.45
1997	S2	14.58	49.11	10.21												0.5
1997	S3	61.94	39.54	0												0
1997	S4	79.08	57.86	0												0
1997	S5	46.03	26.28	0												0
1997	S6	9.69	60.6	0												0
total		**311.22**	**302.38**	**16.16**												**10.95**
2000s																
2000	S1	104.52	66.62	6.36												9.33
2000	S2	14.48	46.34	9.57												0.54
2000	S3	65.11	36.62	0												0
2000	S4	93.1	41.66	0												0
2000	S5	47.8	23.7	0												0
2000	S6	10.52	59.88	0												0
total		**335.52**	**274.82**	**15.93**												**9.87**
Location 8																
1940s																
1941	S1	59.66	44.19	0		0					0				2.59	
1941	S2	35.44	5.72	0		0					0				1.57	
	(S3)	NA	NA	NA		NA					NA				NA	
	(S4)	NA	NA	NA		NA					NA				NA	
	(S5)	NA	NA	NA		NA					NA				NA	
	(S6)	NA	NA	NA		NA					NA				NA	
total		**95.10**	**49.91**	**0**		**0**					**0**				**4.16**	

Appendix 7 (continued) *Change in land cover and habitat (ha) by Location and Site.*

		Natural vegetation	Agricultural land	Residential land	Industrial area	Golf course	Golf park	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
1950s																
1954	S1	60.77	38.32	0		0					0				2.9	
1954	S2	32.78	6.43	0		0					0				1.41	
1954	S3	13.5	47.88	2.87		0					0				0	
1954	S4	12.07	30.71	0		0					0				0	
1954	S5	15.06	30.88	0		0					0				0	
	(S6)	NA	NA	NA		NA					NA				NA	
total		**134.18**	**154.22**	**2.87**		**0**					**0**				**4.31**	
1980s																
1986	S1	63.32	41.68	0		0					0				6.04	
1986	S2	35	5.79	0		0					0				1.39	
1986	S3	13.38	18.54	13.57		18.18					0				0	
1985	S4	12.26	31.89	0		0					0				0	
1985	S5	15.96	30.82	0		0					0				0	
1985	S6	46.53	32.05	4.53		0					2.6				0	
total		**186.45**	**160.76**	**18.1**		**18.18**					**2.6**				**7.43**	
1990s																
1997	S1	63.67	37.98	0		0					0				7.14	
1997	S2	35	5.79	0		0					0				1.39	
1997	S3	13.11	16.07	11.63		22.6					0				0	
1992	S4	12.61	31.13	0		0					0				0.12	
1992	S5	13.39	32.42	0		0					0				0	
1992	S6	45.45	32.11	4.23		0					2.39				0	
total		**183.23**	**155.5**	**15.86**		**22.6**					**2.39**				**8.65**	

Appendix 7 (continued) *Change in land cover and habitat (ha) by Location and Site.*

		Natural vegetation	Agricultural land	Residential land	Industrial area	Golf course	Golf park	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
2000s																
2000	S1	63.55	39.4	0		0					0				8.02	
2000	S2	33.8	5.59	0		0					0				1.61	
2000	S3	11.41	17.66	9.33		24.32					0				0	
2003	S4	13.97	29.93	0		0					0				0.1	
2003	S5	12.86	32.08	0		0					0				0	
2003	S6	48.12	30.22	4.44		0					2.52				0	
total		**183.72**	**154.89**	**13.78**		**24.32**					**2.52**				**9.73**	
Location 9																
1940s																
	(S1)	NA	NA	NA							NA					
	(S2)	NA	NA	NA							NA					
	(S3)	NA	NA	NA							NA					
	(S4)	NA	NA	NA							NA					
	(S5)	NA	NA	NA							NA					
	(S6)	NA	NA	NA							NA					
total																
1950s																
	(S1)	NA	NA	NA							NA					
	(S2)	NA	NA	NA							NA					
	(S3)	NA	NA	NA							NA					
	(S4)	NA	NA	NA							NA					
	(S5)	NA	NA	NA							NA					
	(S6)	NA	NA	NA							NA					
total																

Appendix 7 (continued) *Change in land cover and habitat (ha) by Location and Site.*

		Natural vegetation	Agricultural land	Residential land	Industrial area	Golf course	Golf park	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
1980s																
1985	S1	33.89	14.82	0							0					
1985	S2	39.57	24.69	2.45							1.05					
1985	S3	25.5	63.22	7.59							0					
1985	S4	14.34	18.99	0							0					
1985	S5	24.79	44.28	6.76							0.5					
1985	S6	35.65	41.8	11.8							0					
total		**173.72**	**207.81**	**28.6**							**1.54**					
1990s																
1992	S1	30	19.25	0							0					
1992	S2	40.28	24.26	2.46							0.99					
1992	S3	25.36	62.9	8.16							0					
1992	S4	7.59	23.25	0							1.37					
1992	S5	23.09	43.47	7.12							0.94					
1992	S6	35.73	41.62	12.37							0					
total		**162.05**	**214.75**	**30.11**							**3.3**					
2000s																
2003	S1	35.3	14.13	0							0					
2003	S2	45.5	17.19	2.39							1.13					
2003	S3	33.33	53.81	9.79							0					
2003	S4	19.14	13.65	0							0					
2003	S5	30.78	37.61	6.78							0.5					
2003	S6	39.57	36.59	12.08							0					
total		**203.62**	**172.97**	**31.04**							**1.63**					

Appendix 7 (continued) *Change in land cover and habitat (ha) by Location and Site.*

		Natural vegetation	Agricultural land	Residential land	Industrial area	Golf course	Golf park	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
Location 10																
1940s																
	(S1)	NA	NA	NA							NA					
1949	S2	82.93	31.37	0							5.34					
1949	S3	39.16	95.33	0							4.84					
1949	S4	3.23	151.24	0							0					
1949	S5	1.52	42.72	47.00							0					
1949	S6	15.48	86.19	0							0					
total		**141.32**	**406.85**	**47.00**							**10.18**					
1950s																
	(S1)	NA	NA	NA							NA					
	(S2)	NA	NA	NA							NA					
	(S3)	NA	NA	NA							NA					
	(S4)	NA	NA	NA							NA					
	(S5)	NA	NA	NA							NA					
	(S6)	NA	NA	NA							NA					
total																
1980s																
1985	S1	26.91	73.05	5.91							0.58					
1985	S2	85.04	27.56	5.26							0.86					
1985	S3	36.71	89.57	7.51							1.85					
1986	S4	3.59	134.75	13.62							0					
1986	S5	0.53	35.12	58.84							0					
1986	S6	21.02	64.3	12.63							0					
total		**173.8**	**424.36**	**103.77**							**3.29**					

Appendix 7 (continued) *Change in land cover and habitat (ha) by Location and Site.*

		Natural vegetation	Agricultural land	Residential land	Industrial area	Golf course	Golf park	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
1990s																
1992	S1	26.1	75.91	4.32							0.51					
1992	S2	84.08	28.07	5.18							0.7					
1992	S3	46.32	76.4	11.16							2.27					
1991	S4	2.68	134.85	13.68							0					
1991	S5	0.35	34.86	59.37							0					
1991	S6	20.31	64.7	13.13							0					
total		**179.85**	**414.78**	**106.84**							**3.47**					
2000s																
2003	S1	29.89	69.59	5.43							0					
2003	S2	85.78	26.83	4.81							0.75					
2003	S3	64.82	55.3	15.5							0					
2002	S4	9.48	123.38	18.03							0					
2002	S5	5.05	24.4	65.52							0					
2002	S6	29.17	54.89	14.74							0					
total		**224.19**	**354.38**	**124.04**							**0.75**					
Location 11																
1940s																
1949	S1	4.12	94.73	0	0				0		0					
1949	S2	1.03	53.87	0	0				0		0					
1949	S3	1.38	35.05	0	0				12.52		0					
1949	S4	6.1	27.12	0	0				34.15		0					
1949	S5	6.89	66.94	0	0				0		0					
1949	S6	34.39	51.26	0	0				45.32		0					
total		**53.9**	**328.98**	**0**	**0**				**91.99**		**0**					

Appendix 7 (continued) *Change in land cover and habitat (ha) by Location and Site.*

		Natural vegetation	Agricultural land	Residential land	Industrial area	Golf course	Golf park	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
1950s																
1955	S1	6.19	92.84	2.46	0				0		0					
1955	S2	1.34	50.98	0	0				0		0					
1955	S3	2.63	32.46	0	0				12.37		0					
1955	S4	2.55	28.6	0	0				33.87		0					
1955	S5	17.74	55.96	0	0				0		0					
1955	S6	40.78	34.7	0	0				52.32		0					
total		**71.23**	**295.53**	**2.46**	**0**				**98.56**		**0**					
1980s																
1986	S1	20.32	36.19	37.46	3.45				0		1.71					
1986	S2	1.54	52.08	0	0				0		0					
1986	S3	9.78	25.91	0	0				11.64		0					
1986	S4	13.33	12.12	0	0				28.78		0					
1986	S5	26.16	48.01	0	0				0		0					
1986	S6	56.63	29.82	0	0				24.78		0					
total		**127.74**	**204.13**	**37.46**	**3.45**				**65.19**		**1.71**					
1990s																
1994	S1	15.39	35.55	42.36	3.53				0		1.74					
1994	S2	2.86	50.88	0	0				0		0					
1994	S3	12.21	24.22	0	0				12.43		0					
1994	S4	14.59	13.94	0	0				28.41		1.51					
1994	S5	24.92	49.15	0	0				0		0					
1994	S6	72.83	24.06	0	0				27.47		0					
total		**142.79**	**197.8**	**42.36**	**3.53**				**68.31**		**3.25**					

Appendix 7 (continued) *Change in land cover and habitat (ha) by Location and Site.*

		Natural vegetation	Agricultural land	Residential land	Industrial area	Golf course	Golf park	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
2000s																
2002	S1	18.29	30.28	45.09	3.25				0		2.14					
2002	S2	5.15	48.64	0	0				0		0					
2002	S3	17.57	24.98	0	0				5.81		0					
2002	S4	23.02	24.19	0	0				6.2		1.76					
2002	S5	35.79	38.18	0	0				0		0					
2002	S6	97.72	9.6	0	0				16.55		0					
total		**197.54**	**175.89**	**45.09**	**3.25**				**28.56**		**3.91**					
Location 12																
1940s																
1949	S1	0.14	56.74	0	0	0	0			16.16						
1949	S2	35.74	30.7	2.41	0	0	0			0						
1949	S3	1	43.97	0	0	0	0			7.74						
1949	S4	0	11.01	0	66.13	0	0			0						
1949	S5	0.9	76.97	13.24	0	0	0			0						
1949	S6	1.66	46.45	0	0	0	0			0						
total		**39.44**	**265.83**	**15.65**	**66.13**	**0**	**0**			**23.9**						
1950s																
1955	S1	0	69.59	0	0	0	0			1.23						
1955	S2	25.53	38.09	4.95	0	0	0			0						
1955	S3	1.24	48.95	0	0	0	0			0.62						
1955	S4	0	14.7	0	60.12	0	0			0						
1955	S5	3.47	72.62	14.04	0	0	0			0						
1955	S6	1.34	48.29	0	0	0	0			0						
total		**31.6**	**292.23**	**18.99**	**60.12**	**0**	**0**			**1.86**						

Appendix 7 (continued) *Change in land cover and habitat (ha) by Location and Site.*

		Natural vegetation	Agricultural land	Residential land	Industrial area	Golf course	Golf park	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
1980s																
1986	S1	5.93	56.42	0	0	0	0			0						
1986	S2	43.97	9.26	13.34	0	0	0			0						
1986	S3	8.83	0	0	42.38	0	0			1.04						
1986	S4	11.86	0	0	61.25	0	0			0						
1986	S5	4.88	5.87	30.01	11.44	0	36.45			0						
1986	S6	3.40	0	33.92	0	4.20	7.28			0						
total		**78.87**	**71.56**	**77.27**	**115.07**	**4.2**	**43.73**			**1.04**						
1990s																
1994	S1	7.12	55.66	0	0	0	0			0						
1994	S2	40.36	10.92	12.86	0	0	0			0						
1994	S3	10.59	0	0	41.00	0	0			1.99						
1994	S4	21.03	0	0	52.03	0	0			0						
1994	S5	5.40	6.18	30.32	11.76	0	36.16			0						
1994	S6	2.47	0	37.59	0	4.14	4.70			0						
total		**86.96**	**72.76**	**80.77**	**104.8**	**4.14**	**40.86**			**1.99**						
2000s																
2002	S1	8.65	54.54	0	0	0	0			0						
2002	S2	38.96	0	26.53	0	0	0			0						
2002	S3	15.76	0	0	39.71	0	0			0						
2002	S4	42.13	0	0	34.02	0	0			0						
2002	S5	6.20	6.12	30.12	11.48	0	35.80			0						
2002	S6	2.95	0	37.37	0	4.04	4.82			0						
total		**114.65**	**60.66**	**94.02**	**85.21**	**4.04**	**40.62**			**0**						

Appendix 7 (continued) *Change in land cover and habitat (ha) by Location and Site.*

		Natural vegetation	Agricultural land	Residential land	Industrial area	Golf course	Golf park	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
Location 13																
1940s																
1949	S1	81.23	0	0			0	0	0	0			0			
1949	S2	56.65	0	0			0	0	0	0			0			
1949	S3	41.14	0	0			0	0	0	0			0			
1949	S4	100.72	0	0			0	0	0	0			0			
1949	S5	27.50	0	0.98			0	0	13.25	0			0			
1949	S6	41.81	0	0			0	0	2.39	0			0			
total		**349.04**	**0**	**0.98**			**0**	**0**	**15.64**	**0**			**0**			
1950s																
1955	S1	78.15	0	0			0	0	0	0			0			
1955	S2	58.45	0	0			0	0	0	0			0			
1955	S3	41.03	0	0			0	0	0	0			0			
1955	S4	94.02	0	0			0	0	0	0			0			
1955	S5	19.03	0	1.52			0	0	23.98	0			0			
1955	S6	36.79	0	0			0	0	5.36	0			0			
total		**327.47**	**0**	**1.52**			**0**	**0**	**29.34**	**0**			**0**			
1980s																
1986	S1	62.4	14.77	0			0	0	0	0			0			
1986	S2	57.91	0	0			0	0	0	0			0			
1986	S3	38.8	1.85	0			0	0	0	0			0			
1986	S4	95.34	2.9	0			0	0	0	0			0			
1986	S5	32.49	0	2.18			6.13	0	3.35	0.82			2.15			
1986	S6	42.23	0	0			0	0.48	0	0			1.44			
total		**329.17**	**19.53**	**2.18**			**6.13**	**0.48**	**3.35**	**0.82**			**3.6**			

Appendix 7 (continued) *Change in land cover and habitat (ha) by Location and Site.*

		Natural vegetation	Agricultural land	Residential land	Industrial area	Golf course	Golf park	Bare sand	Bare earth	Dry riverbed	Reservoir	Roads	Dam wall	Seagrass	Mangrove	Saltmarsh
1990s																
1994	S1	62.12	15.61	0			0	0	0	0			0			
1994	S2	59.08	0	0			0	0	0	0			0			
1994	S3	38.41	2.45	0			0	0	0	0			0			
1994	S4	94.66	2.41	0			0	0	0	0			0			
1994	S5	36.18	0	2.05			5.27	2.07	1.29	0.71			1.75			
1994	S6	41.36	0	0			0	0.51	0	0			1.82			
total		**331.79**	**20.47**	**2.05**			**5.27**	**2.58**	**1.29**	**0.71**			**3.58**			
2000s																
2002	S1	61.83	15.57	0			0	0	0	0			0			
2002	S2	58.16	0	0			0	0	0	0			0			
2002	S3	38.00	2.91	0			0	0	0	0			0			
2002	S4	80.50	16.00	0			0	0	0	0			0			
2002	S5	32.84	0	2.13			5.81	0	3.82	0.45			1.80			
2002	S6	41.42	0	0			0	0	0	1.23			1.22			
total		**312.75**	**34.48**	**2.13**			**5.81**	**0**	**3.82**	**1.68**			**3.02**			

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